Early times and Thermalization

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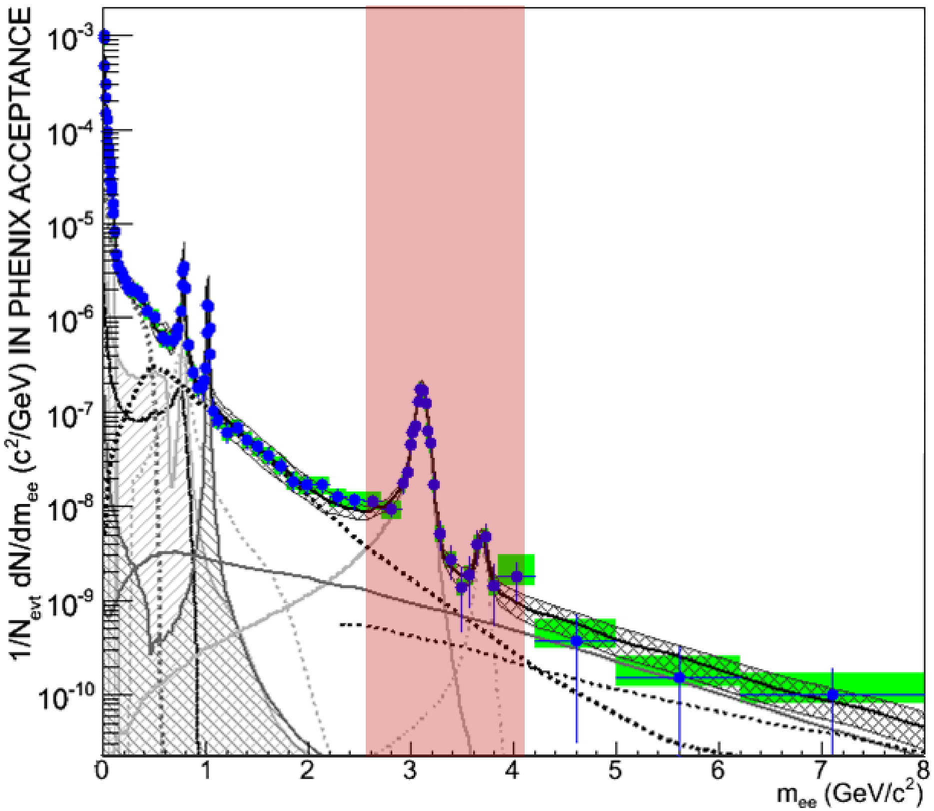
Quark Matter 2009 – April 4 2009

Contents



Di-electron invariant mass spectrum in p+p collisions at RHIC (PHENIX)

PHENIX , PLB 670,313(2009)

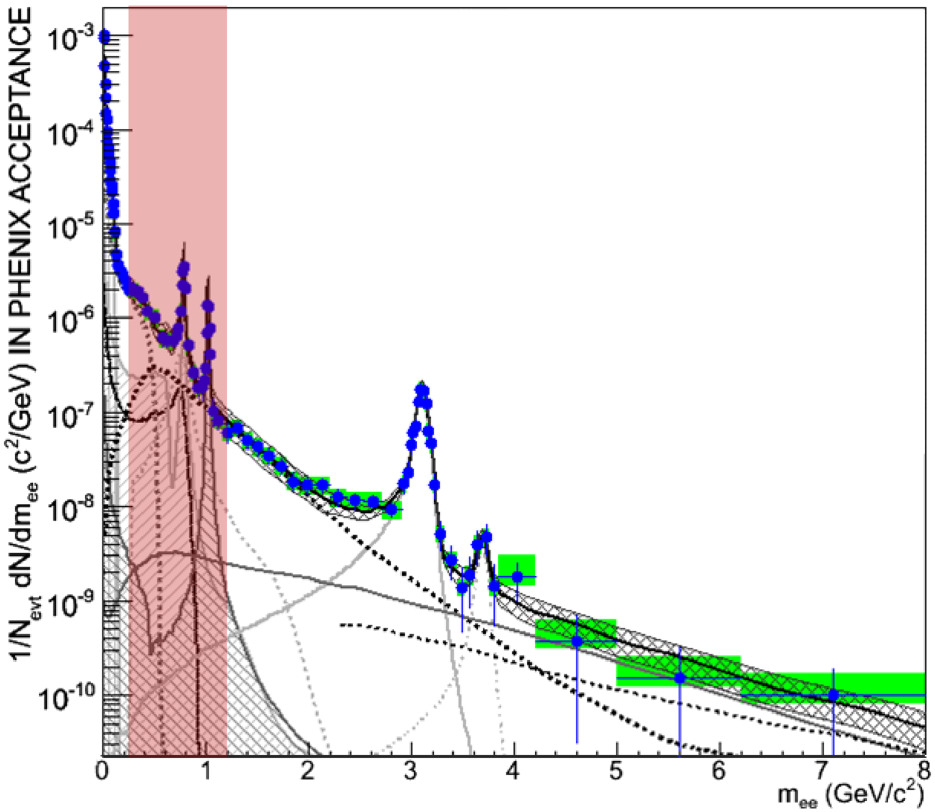
Photons and
low mass dileptons

Open Charm

Open Beauty

Heavy Quarkonia

Photons and low mass di-leptons



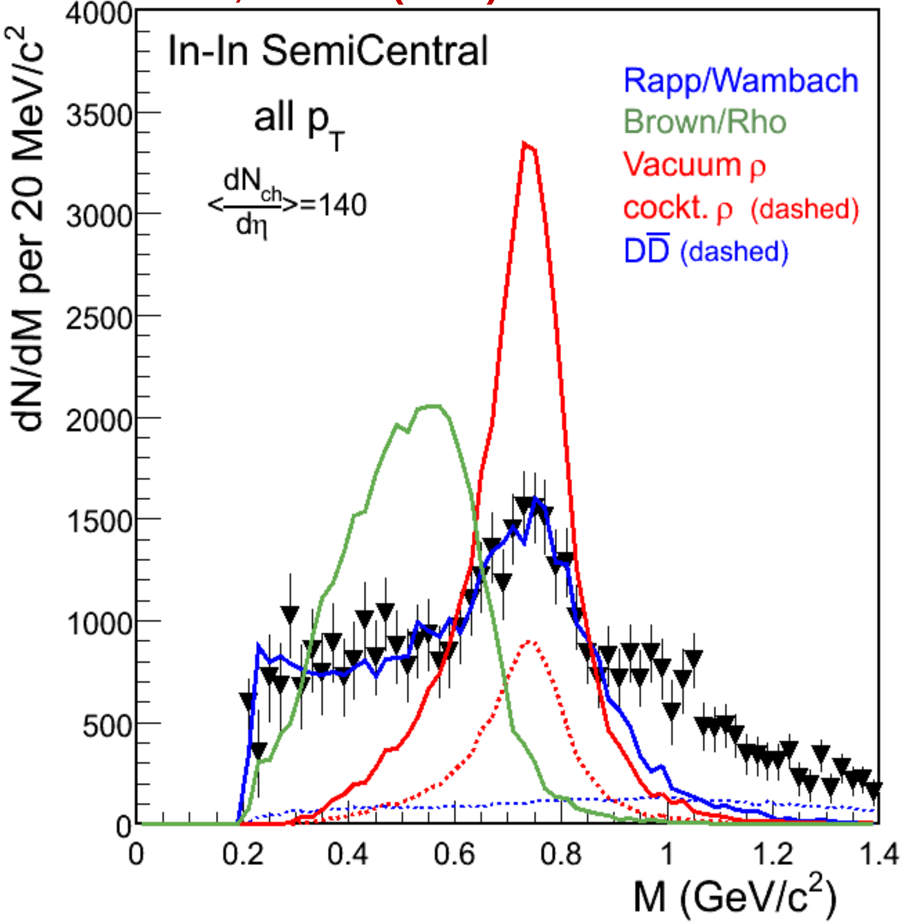
Spectral functions modifications

Chiral symmetry restoration

Temperature of the early medium

Light vector mesons at SPS

NA60, PRL 96 (2006) 162302



Light vector mesons mass spectra are modified in A+A collisions wrt p+p (and vacuum calculations)

models of in medium spectral function modification (here ρ broadening, in blue) describe data below 900 MeV

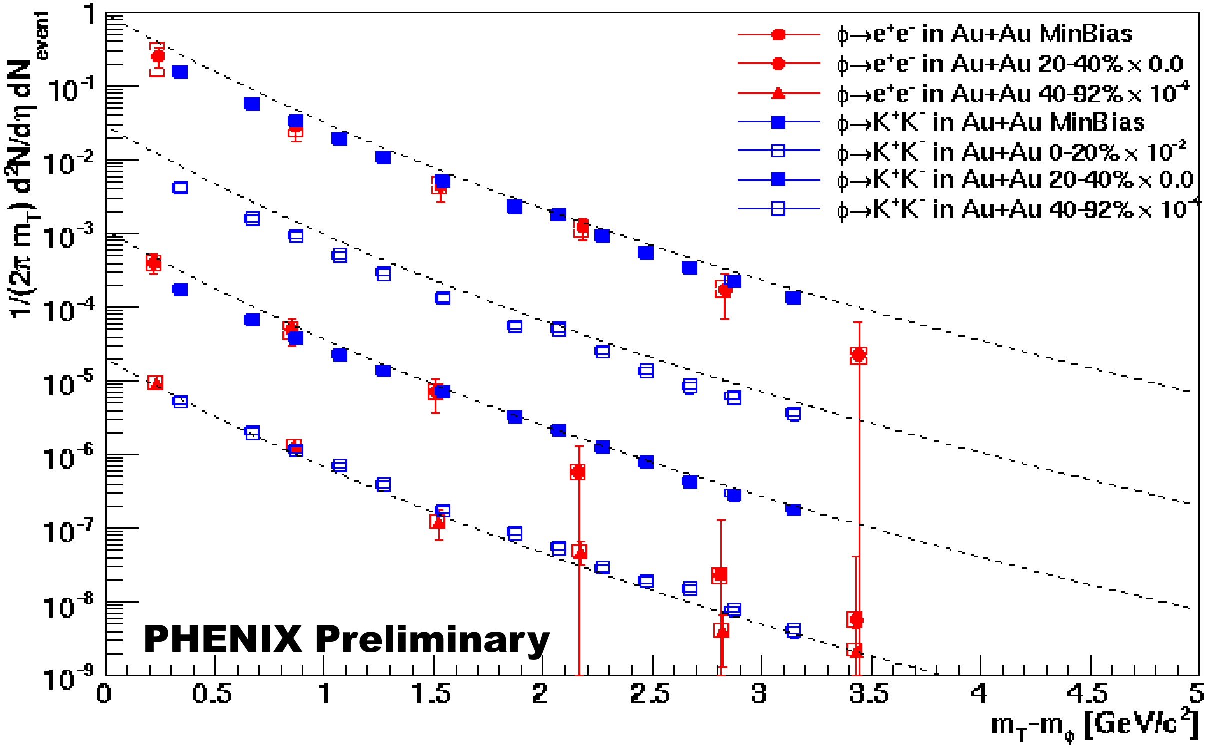
Mostly via $\pi^+\pi^-$ annihilation during transition from QGP to hadronic phase

Room for a chiral symmetry restoration signal ?

Light vector mesons at RHIC

On the other hand, LVM spectral function modification should affect hadronic vs leptonic decay branching ratios.

Here $\phi \rightarrow$ KK versus $\phi \rightarrow$ e+e- at RHIC



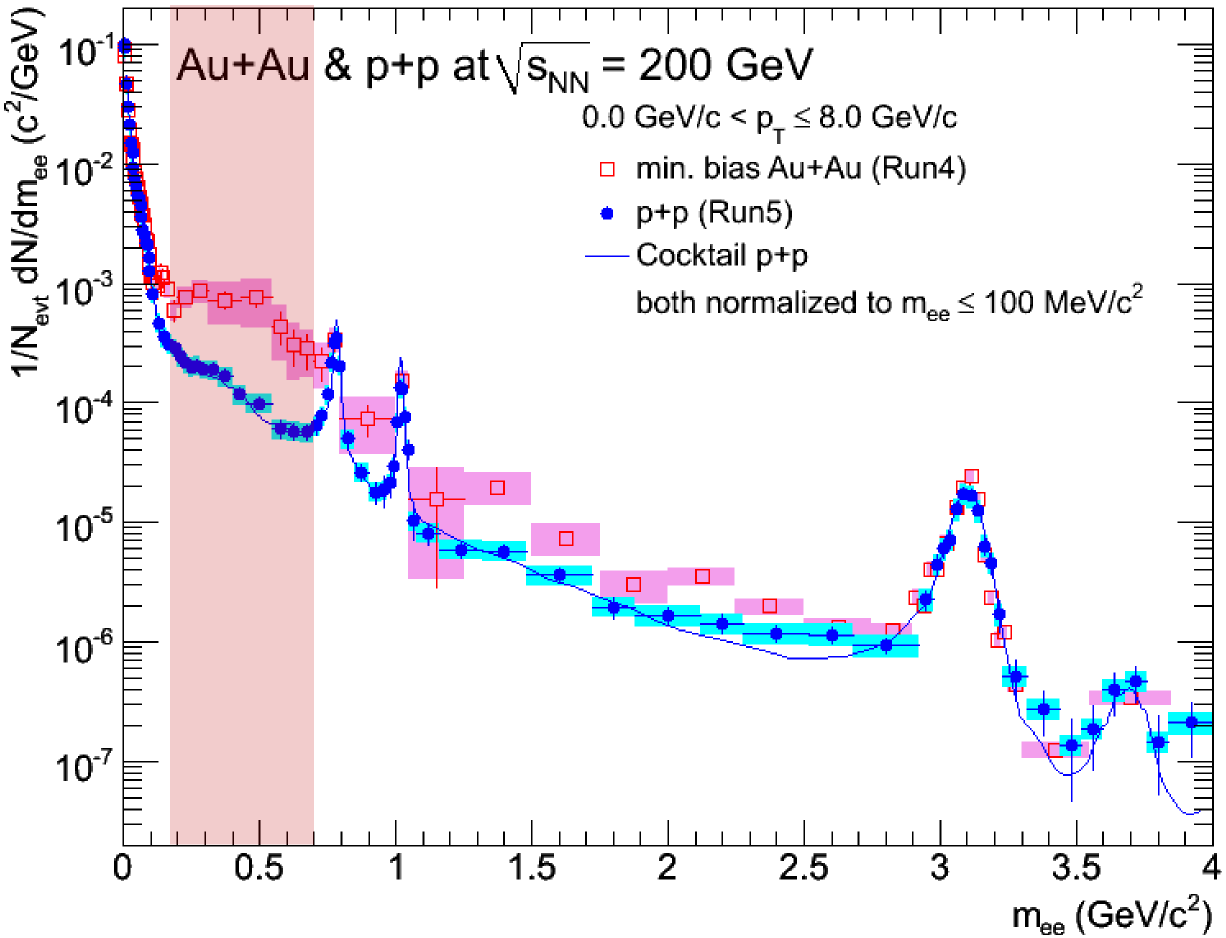
No differences are observed within statistics.

ω and ρ should be more sensitive, but harder to measure

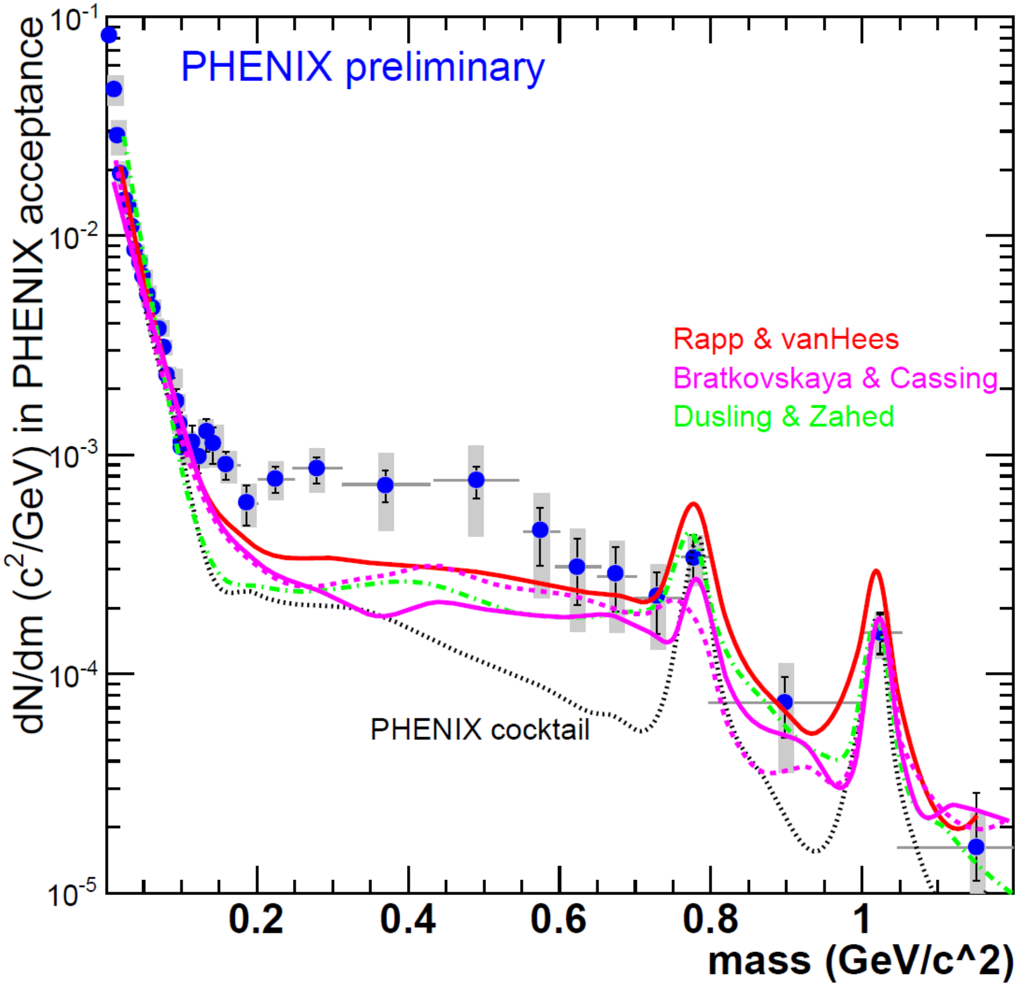
Low mass di-leptons in A+A vs p+p at RHIC

But this is not the whole story …

PHENIX, arXiv: 0706.3034v1 [nucl-ex], PLB 670:313-320,2009



Low mass di-leptons in A+A vs p+p



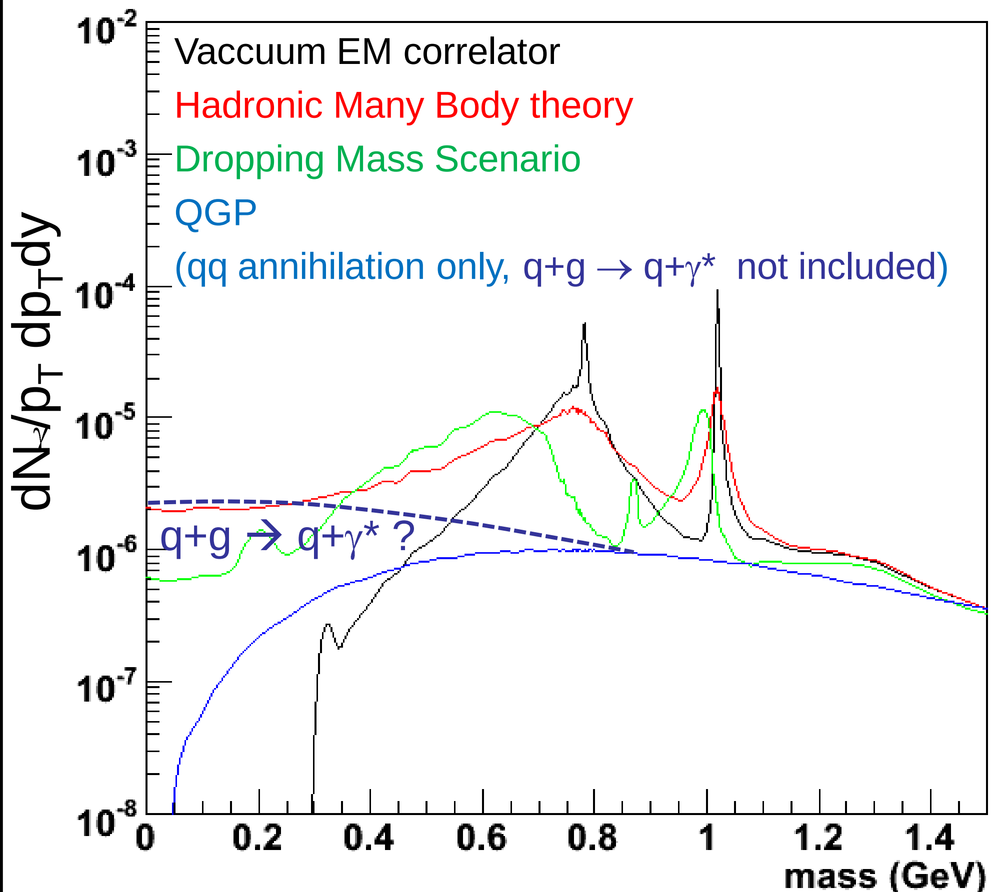
Try ρ broadening (similar to SPS) and mass dumping.

Works ok for m >600 MeV/c2

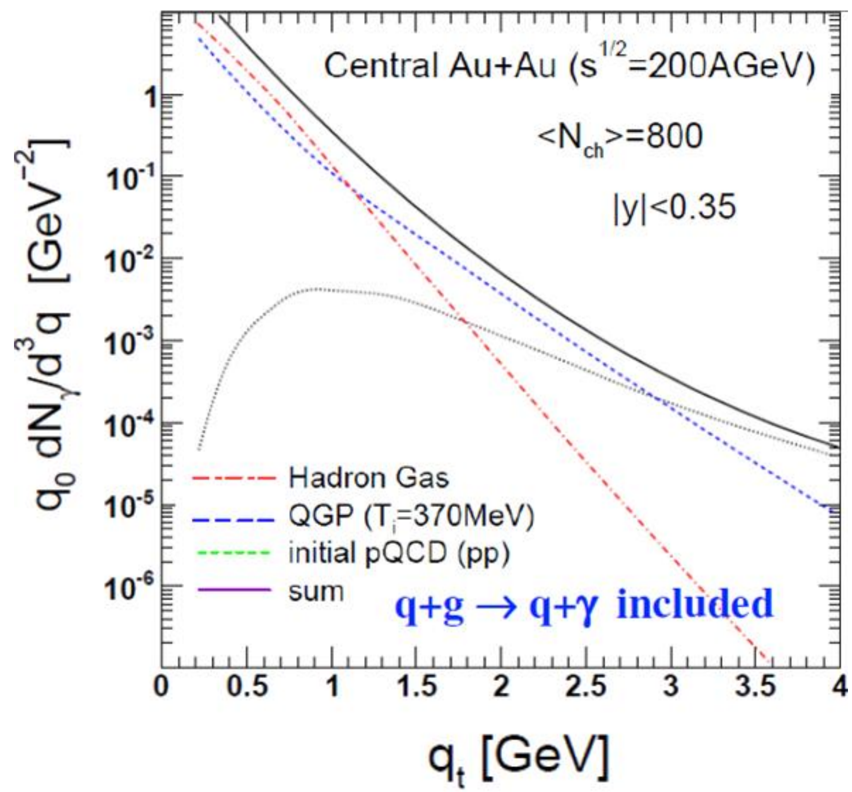
Is insufficient for m in 200 - 600 MeV/c^2

Low mass, low p_T excess (2) Thermal origin ?

Calculation by Ralph Rapp, re-expressed in terms of virtual photon yields



Turbide, Rapp, Gale, PRC 69, 014903 (2004)

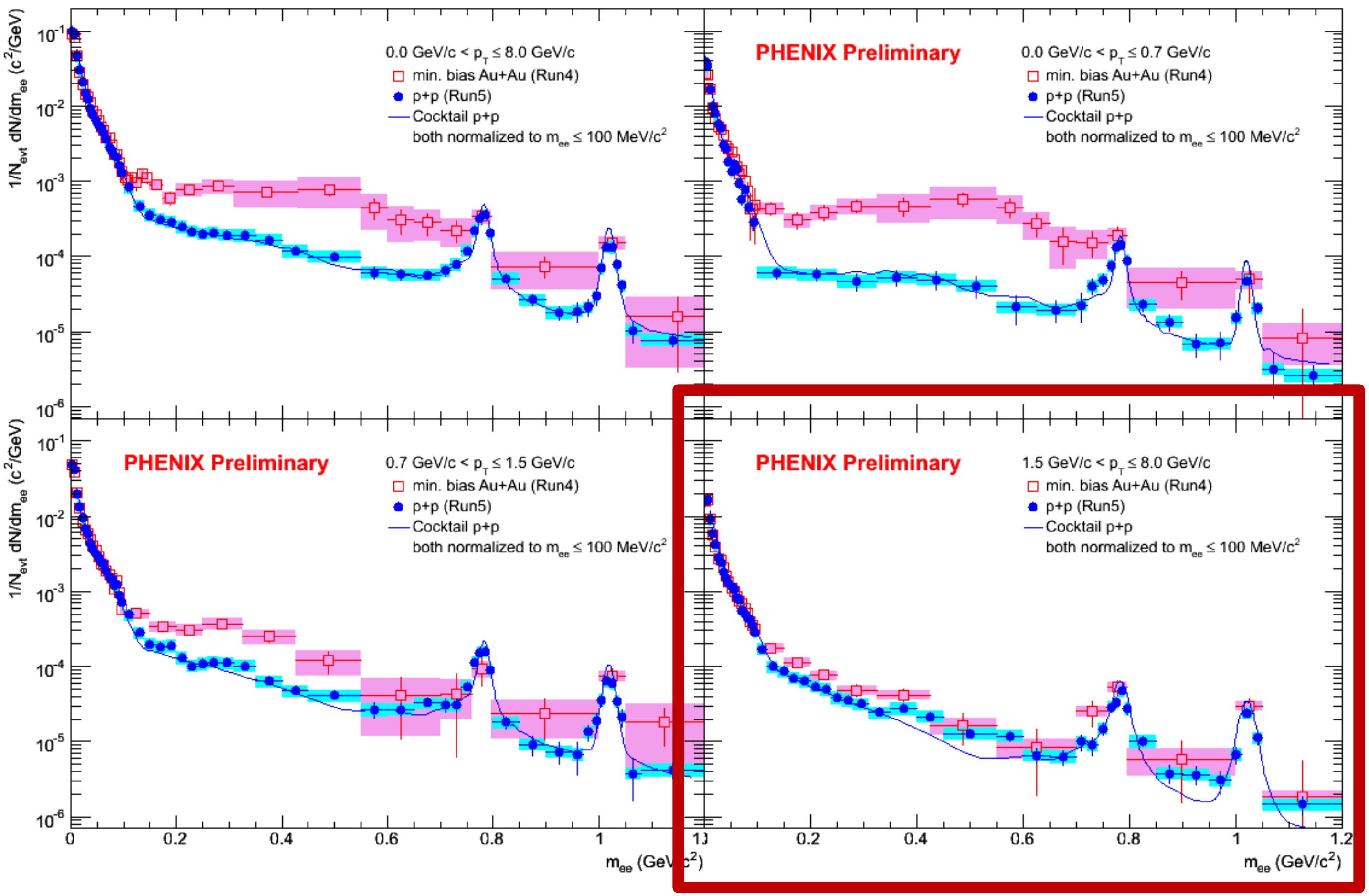


From real photon calculation, the contribution from q+g scattering could be as large as Hadron Gas.

Such contribution might explain some of the remaining excess.

To be continued …

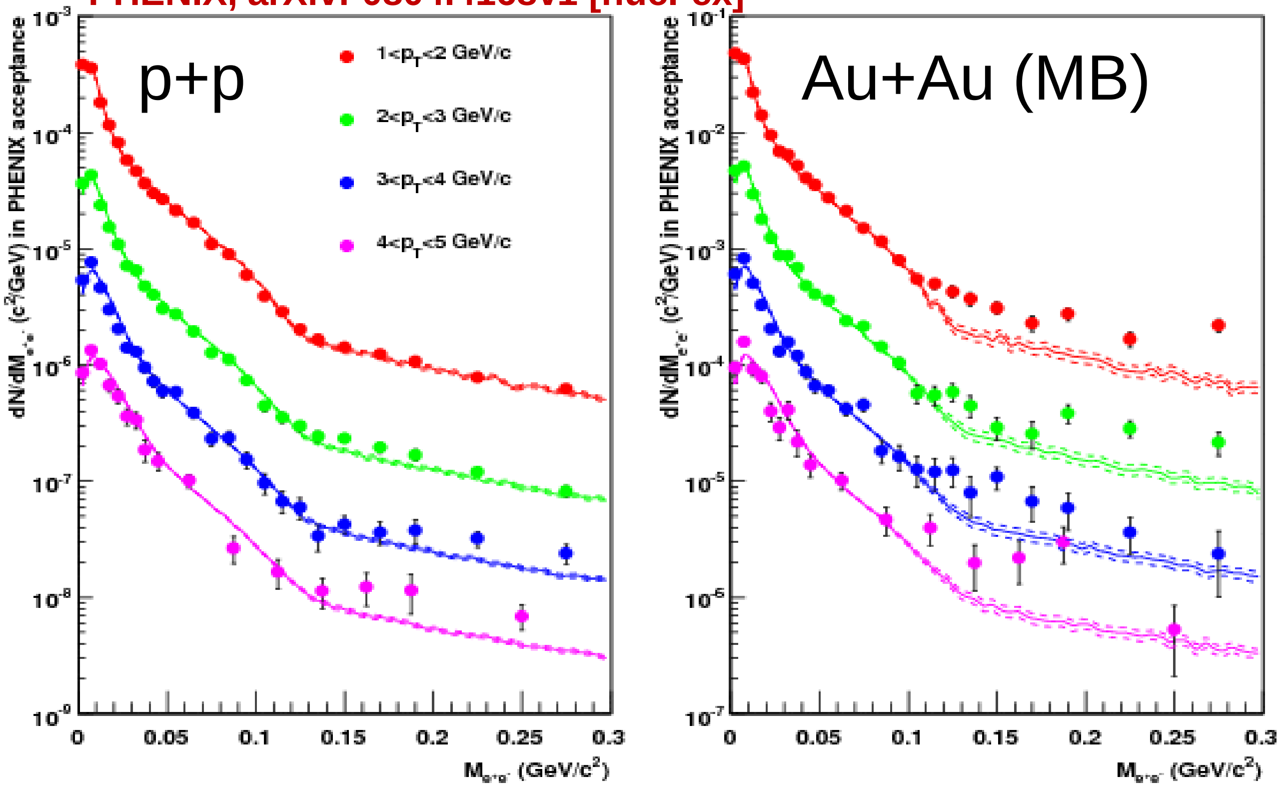
Low mass di-leptons in A+A vs p+p vs p_T



look at high p_T (> 1 Gev/c)

Thermal photons (low mass, p_T>1 GeV)

PHENIX, arXiv: 0804.4168v1 [nucl-ex]

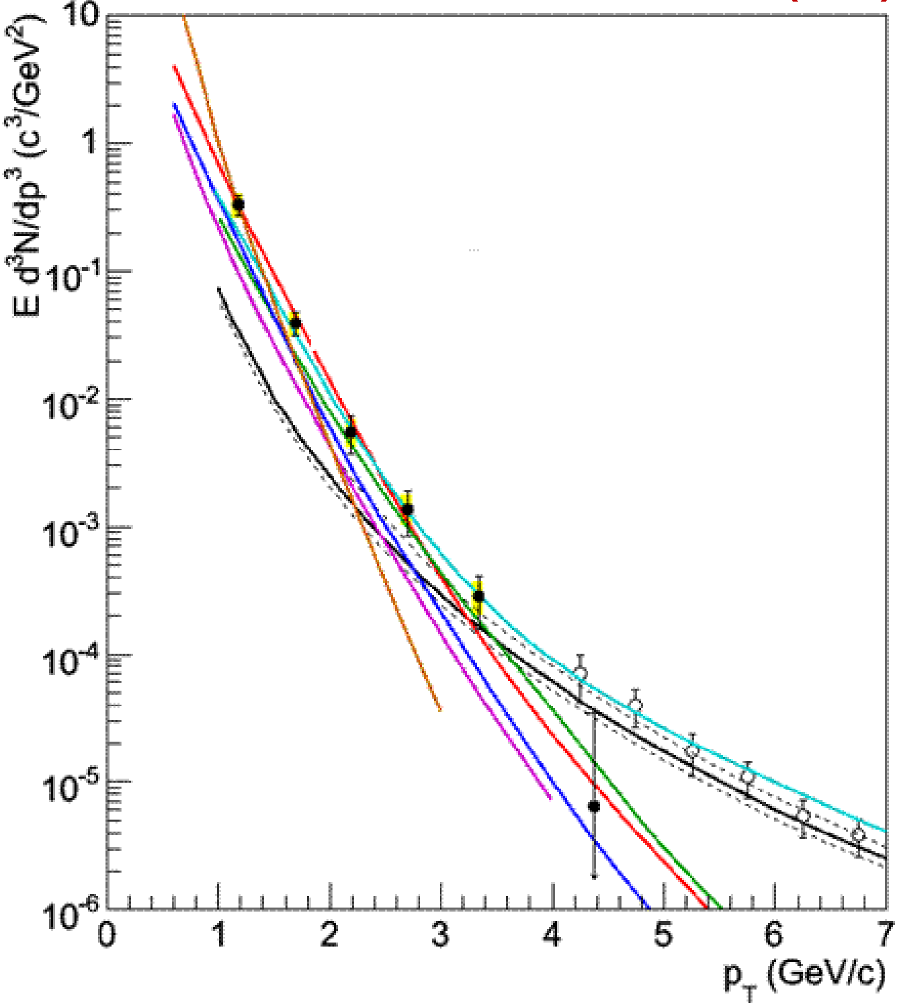


- Look at the excess over estimated hadronic sources (cocktail) as a function of mass for different p_T bins in p+p and A+A.
- Interpret it as <u>virtual</u> photon emmission (for m in 0.1 - 0.3 GeV/c^2)
- Extrapolate to m = 0 to get <u>real</u> photon yields

Thermal photons (low mass, p_T>1) at RHIC

Fit p_T spectra with hydro calculations

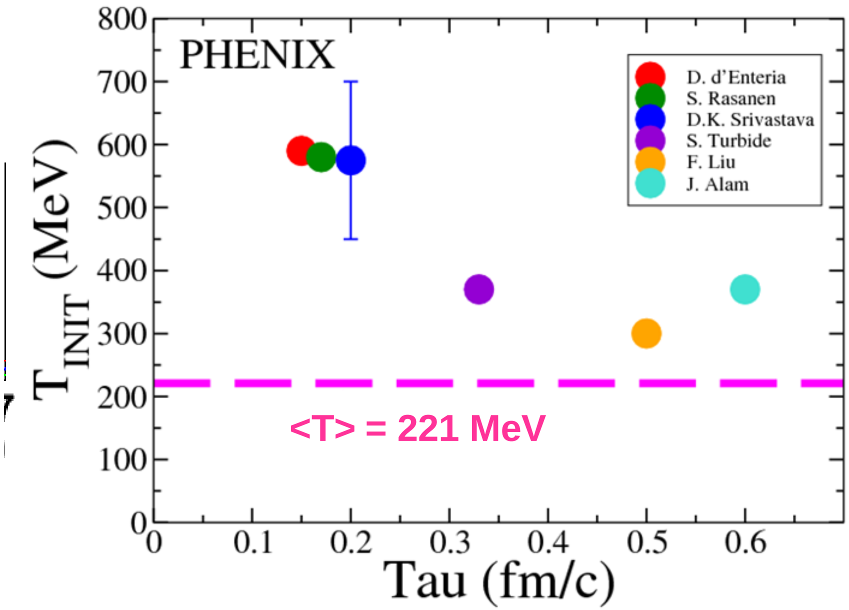
d'Enterria, Peressounko, EPJ C46, 451 (2006)



p_T > 1 GeV/c

$0.1 < M_{ee} < 0.3$ GeV/c^2

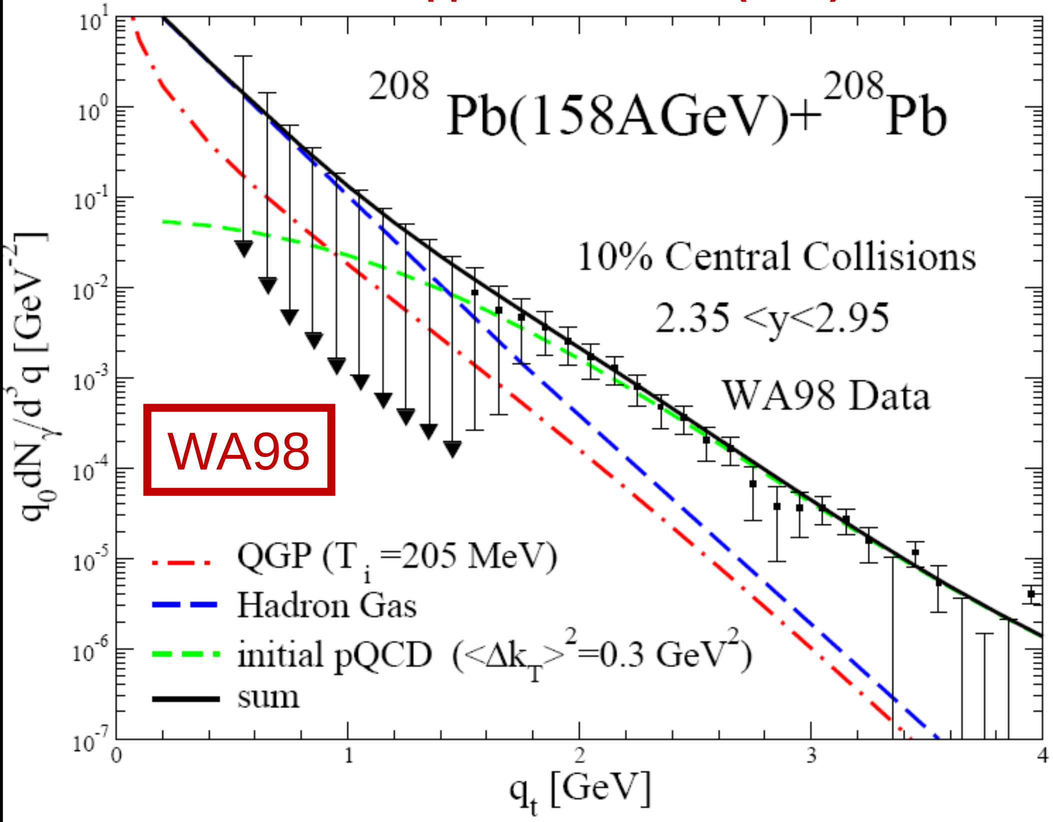
Centrality	<T> (MeV)
0-20 %	221±23±18
20-40 %	215±20±15
0-93%	224±16±19



Real photons at SPS

Data: WA98, PRL 85 (2000) 3595

Theo: Turbide, Rapp, Gale, PRC 69 (2004) 014903

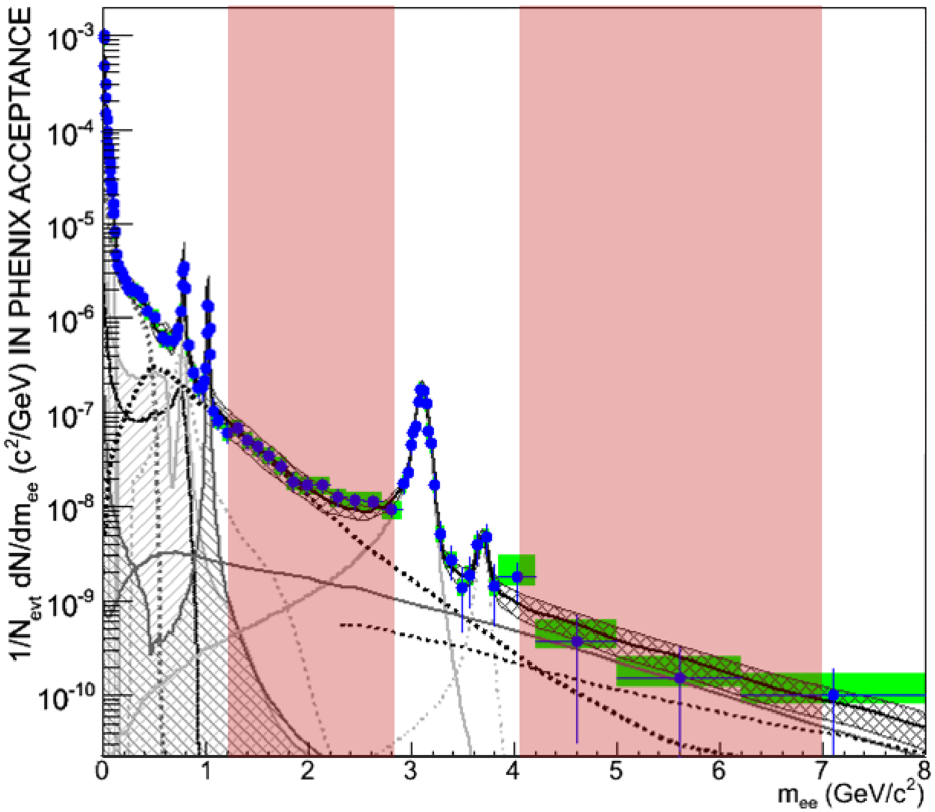


Similar fit to WA98 real photon spectra.

Give initial temperature

T_i = 205 MeV

Heavy flavors

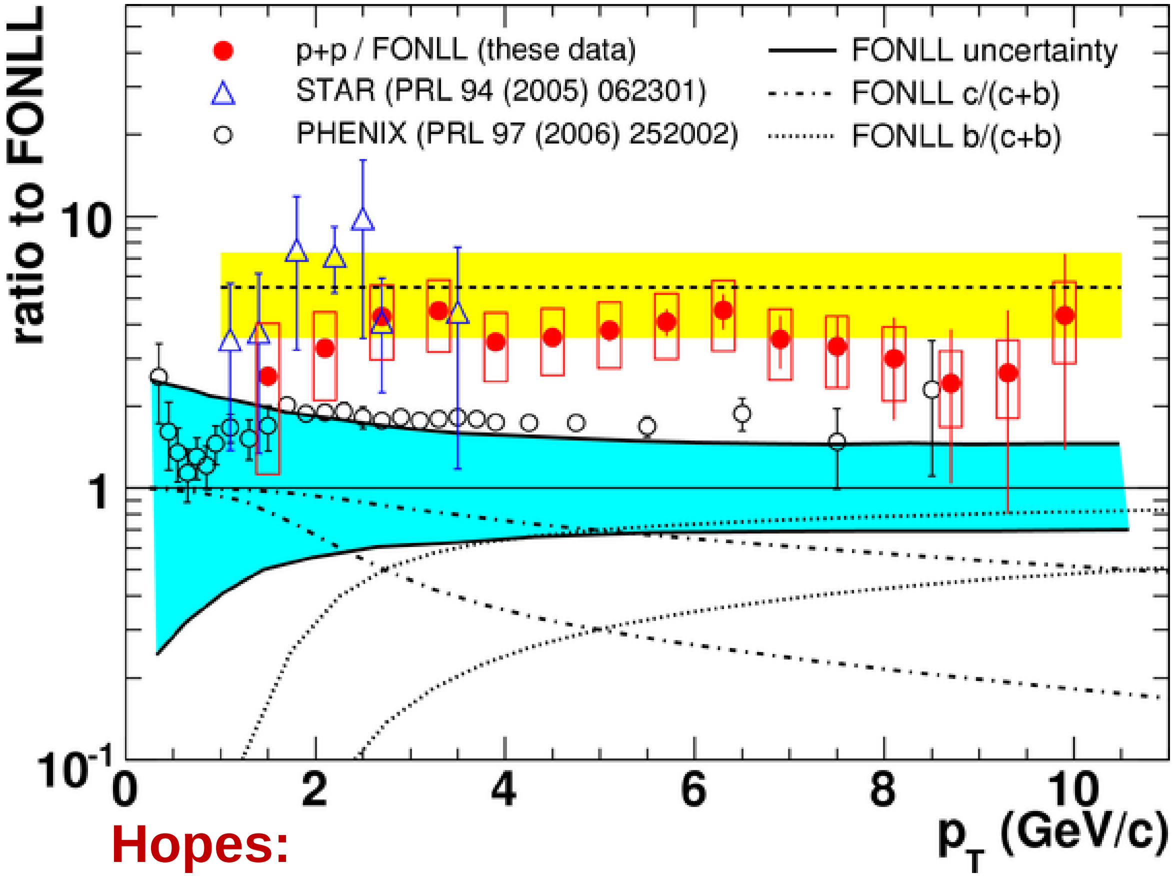


Challenges for

- Experimentalists
- Theoreticians

Differential cross-section vs p_T

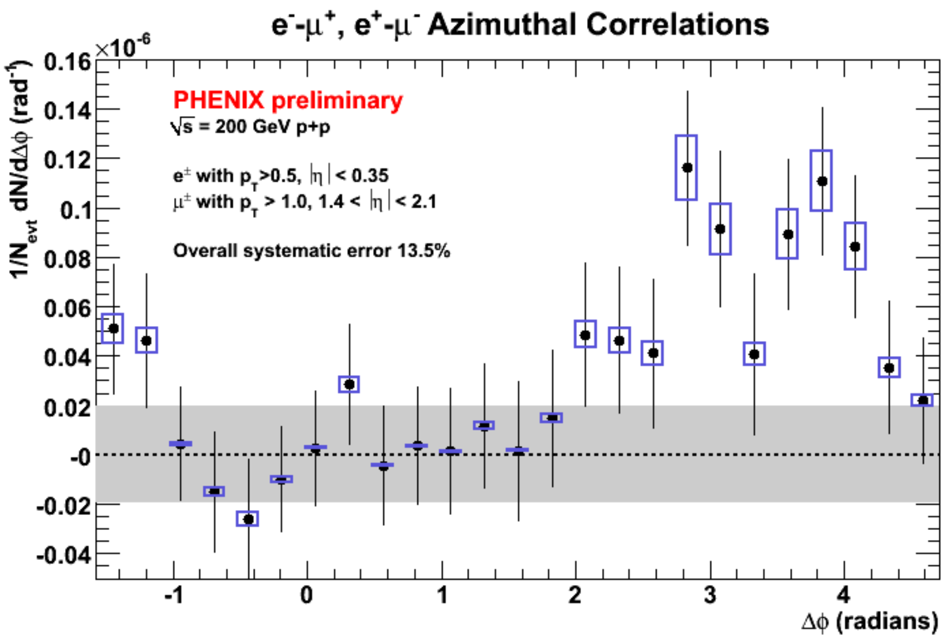
STAR, PRL 98 (2007) 192301



Hopes:

- Direct D reconstruction (STAR)
- Removal of silicon vertex detectors (STAR)
- Better control over background contributions (PHENIX)
- Detector upgrades allowing direct D reconstruction

Total cross-section (in p+p, d+A, A+A)



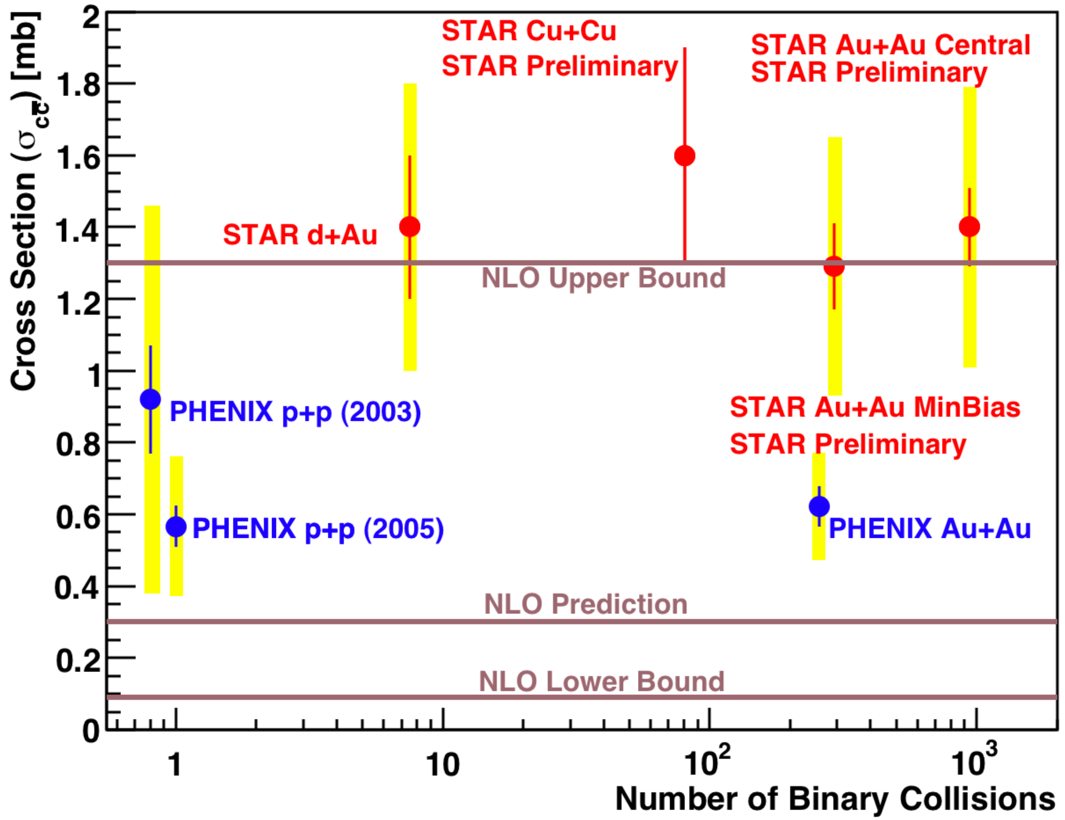
Single electrons (STAR)

Single electrons (PHENIX)

Di-electrons (PHENIX)

Electron-muon correlations (PHENIX)

Total cross-section (in p+p, d+A, A+A)



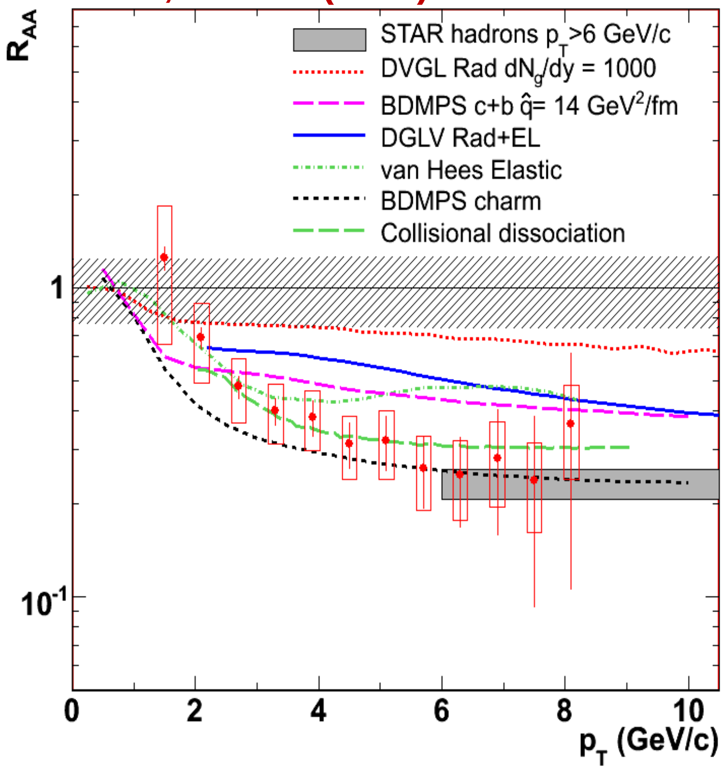
single-electron measurement: σ_{cc} = 567 57 224 μb **Phys. Rev. Lett. 97, 252002 (2006)**

di-electron measurement: σ_{cc} = 544 39 142 μb **arXiv:0802.005v2 [hep-ex]**

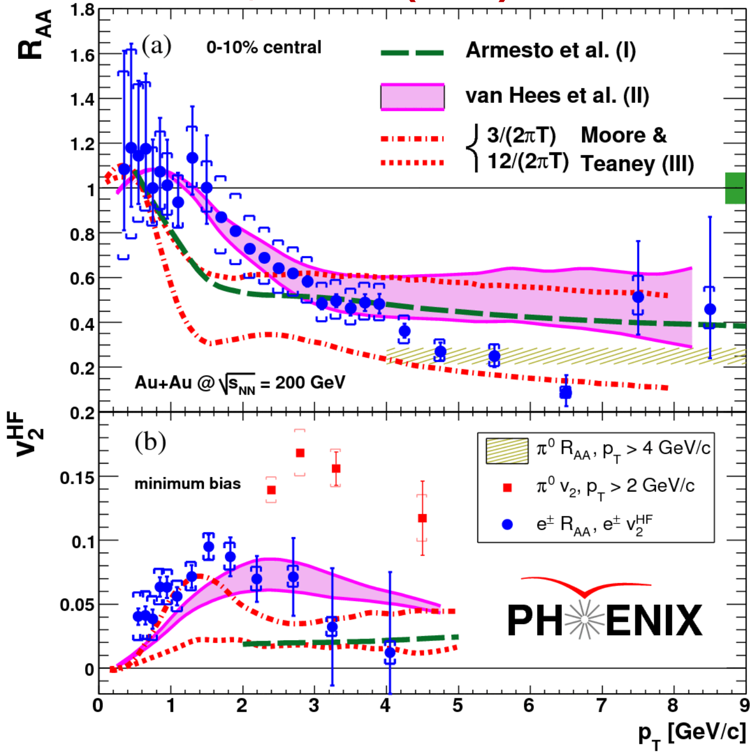
IMHO, no convincing evidence about who is right and who is wrong so far.

Nuclear modification factor in A+A

STAR, PRL 98 (2007) 192301



PHENIX, PRL 98 (2007) 172301



Here PHENIX and STAR agree.

Many models to describe these data (both RAA and v2):

- collisional vs inelastic energy loss
- Langevin + hydro energy loss
- sQGP and shock wave via AdS/CFT
- in-medium fragmentation of c and b
- T-Matrix approach
- Etc.

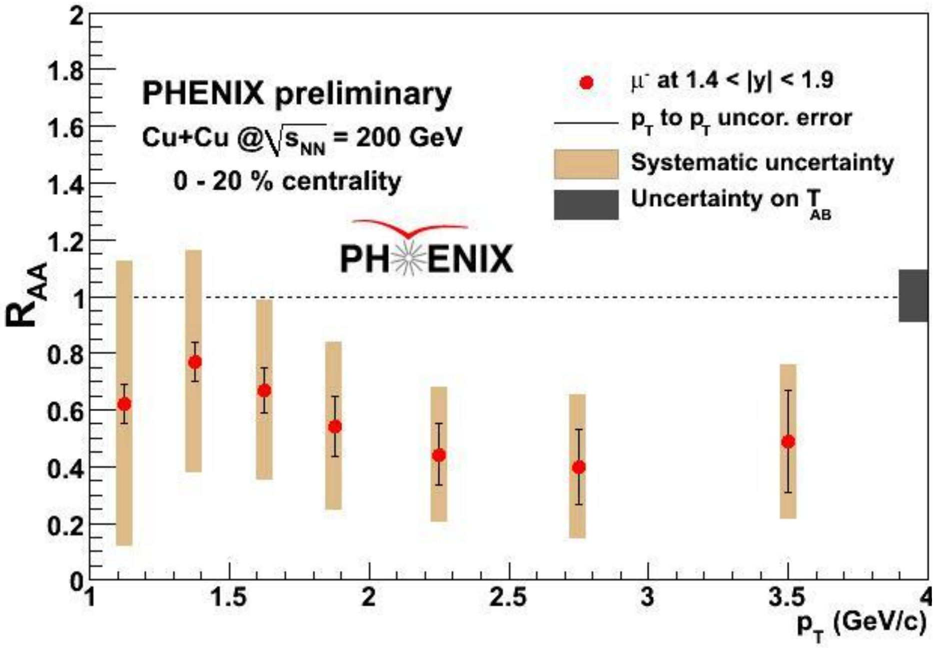
No consensus. Need more measurements.

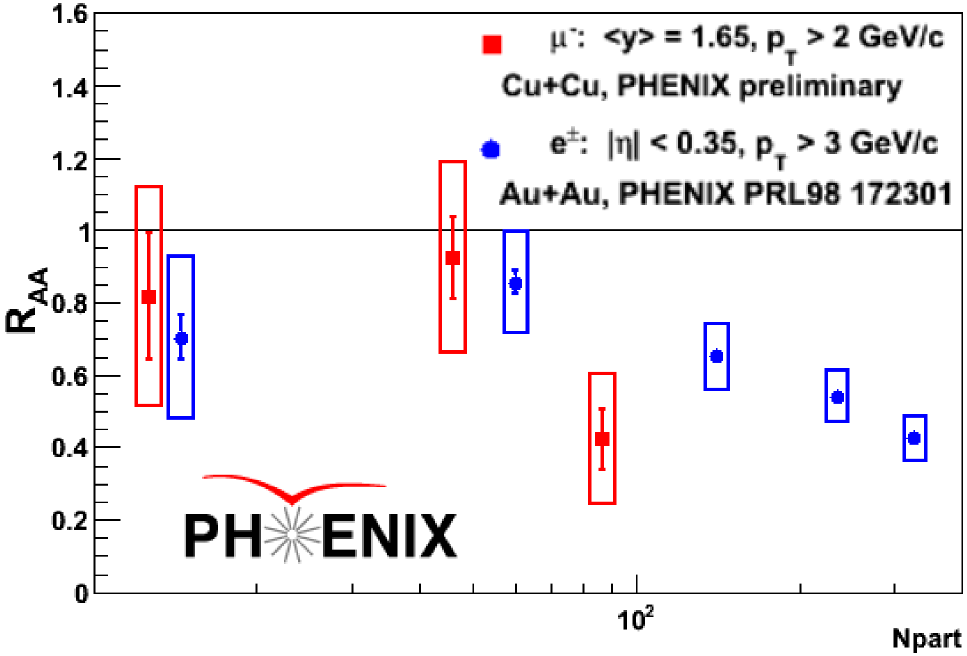
Heavy flavor via single muons at forward rapidity

Heavy flavor measured using forward rapidity PHENIX muon arms

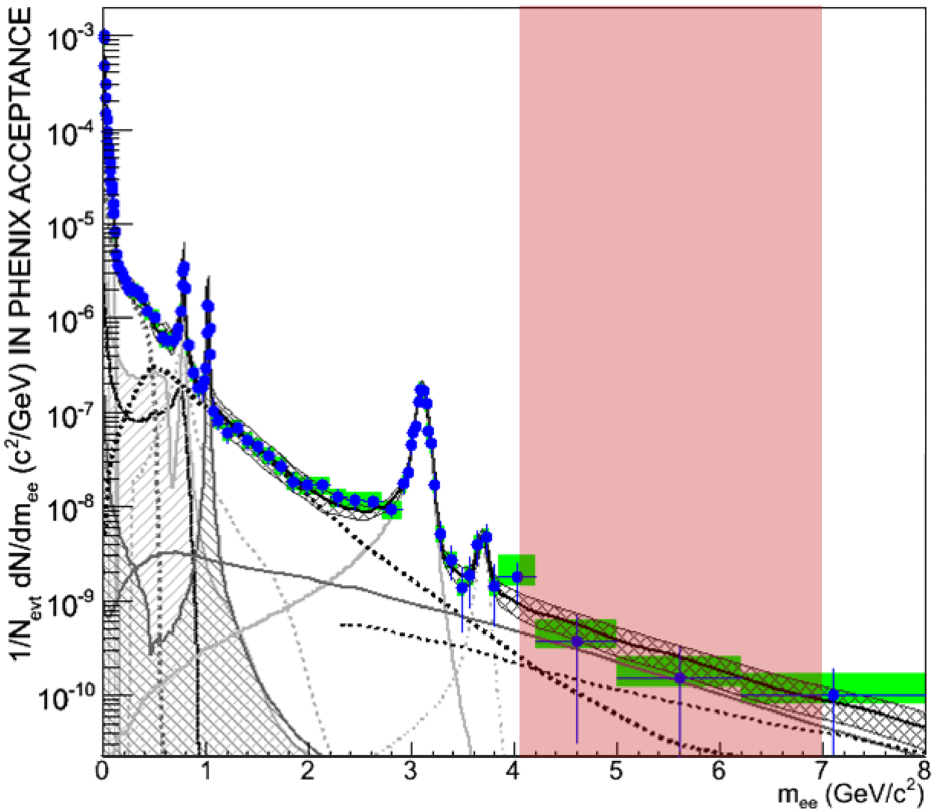
Data-driven hadronic cocktail subtracted from the data in both p+p and Cu+Cu

Systematics dominated by hadronic cocktail and model dependence



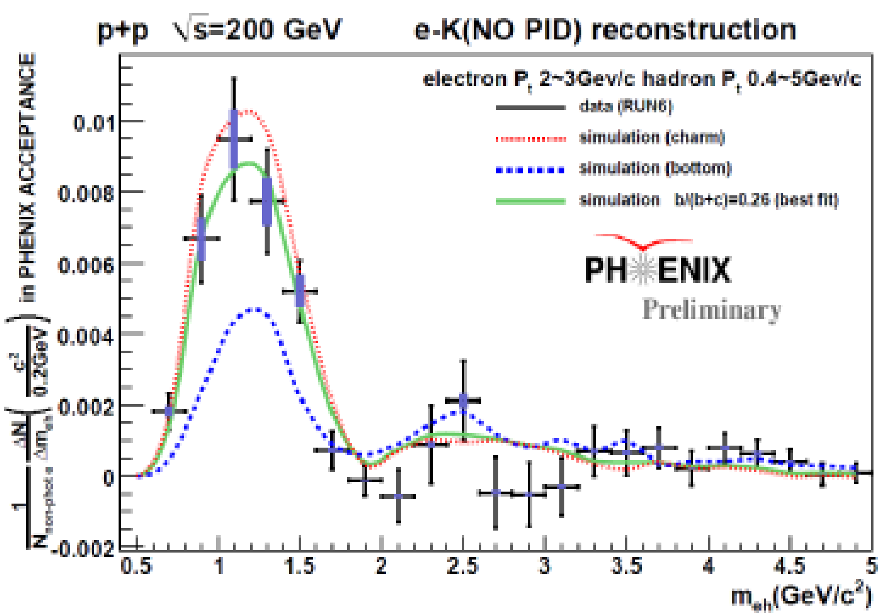


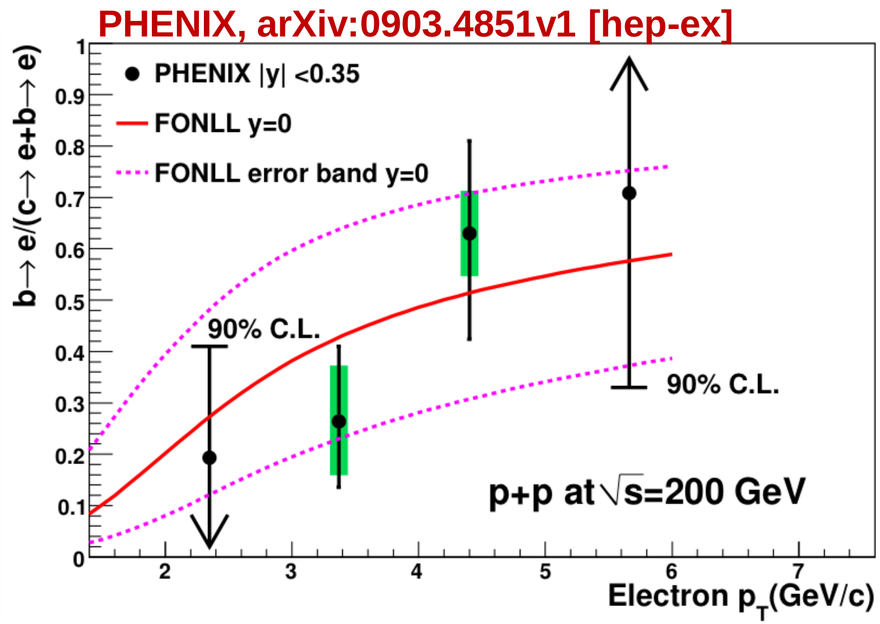
Open beauty



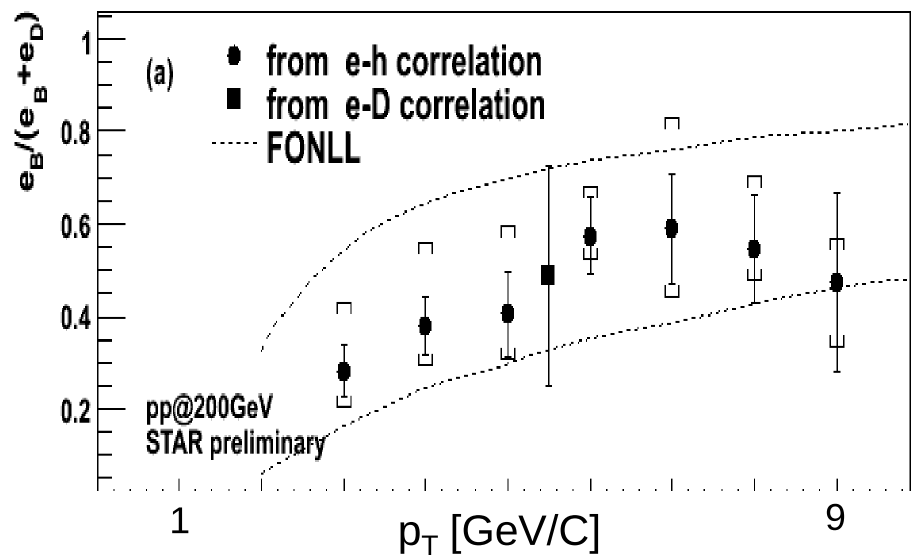
1/N$_{evt}$ dN/dm$_{ee}$ (c^2/GeV) IN PHENIX ACCEPTANCE
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
1
2
3
4
5
6
7
8
m$_{ee}$ (GeV/c^2)

Charm and beauty separation in p+p





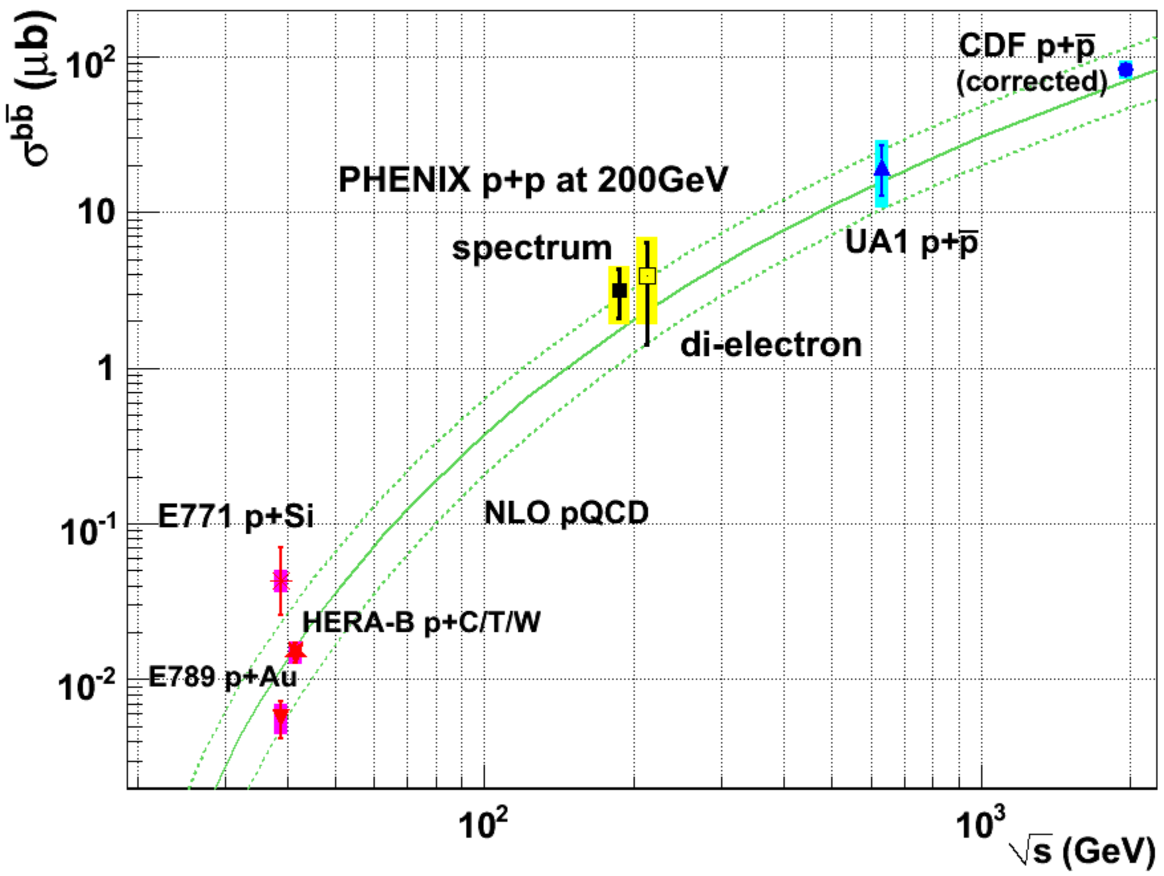
Uses unlike sign electron – hadron correlations, and differences between B and D decay kinematics.



Total B cross-section in p+p

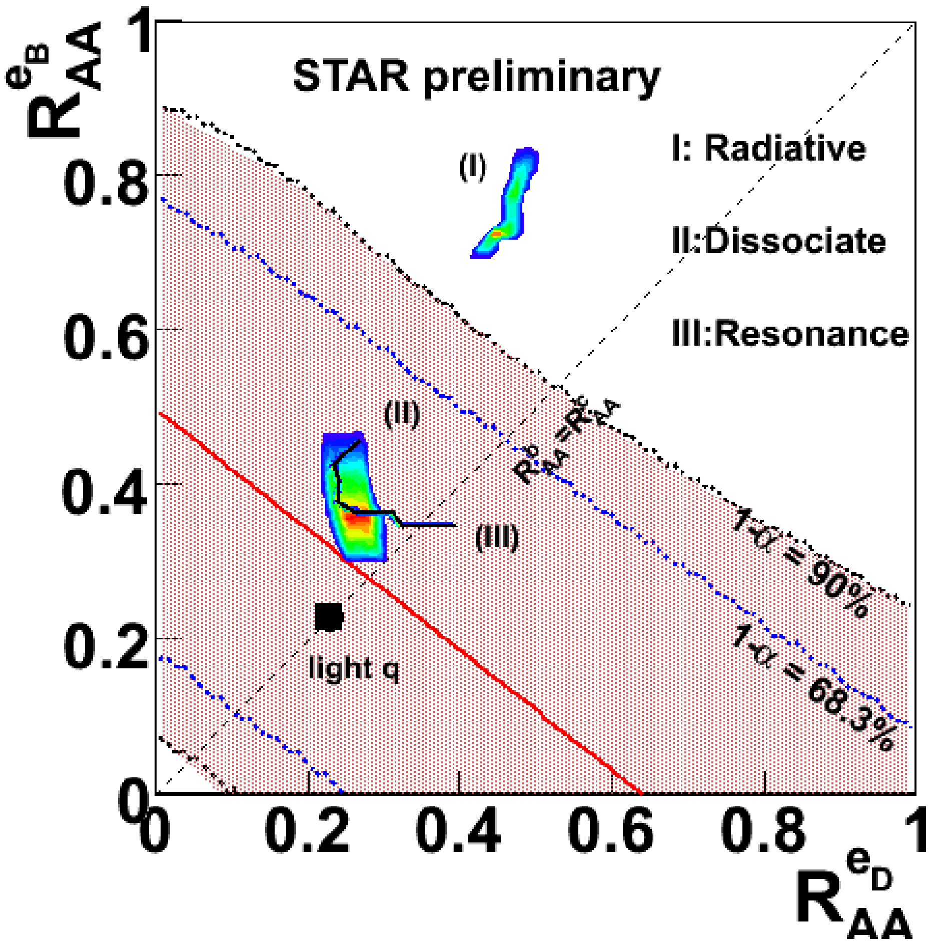
Total cross-section can be derived using either:

- p_T spectra from e-h correlations (STAR or PHENIX)
- Combined c-cbar and b-bbar fit to di-electron spectrum (PHENIX)



Charm and Beauty R_{AA}

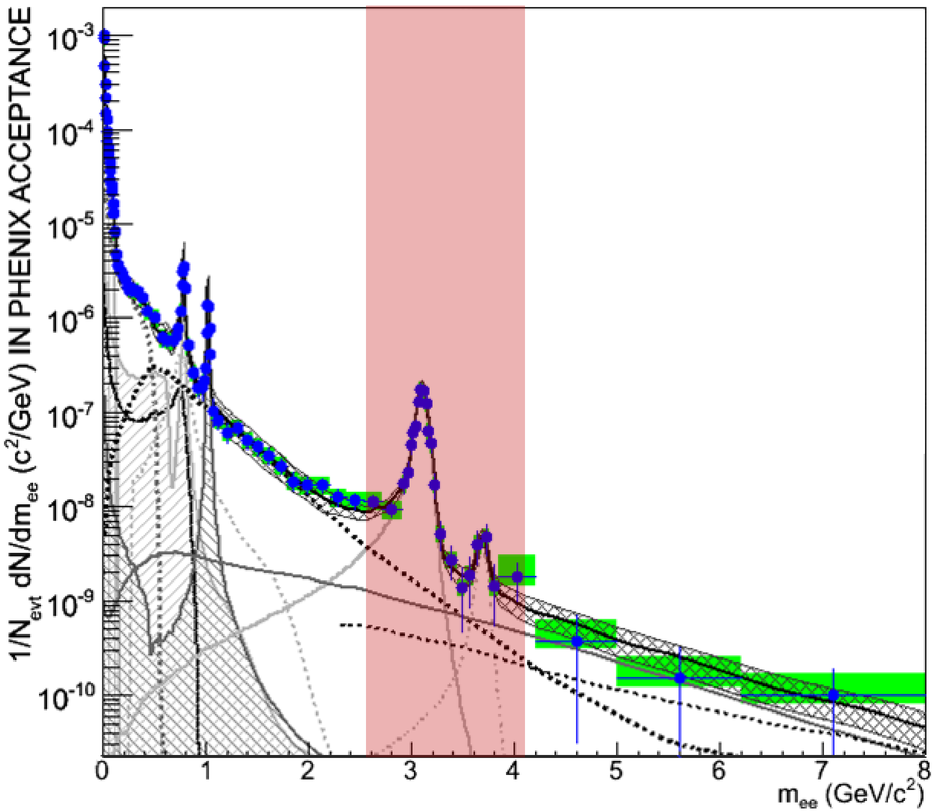
Knowing R_{AA} for c+b electrons, and cross-section in p+p for c and b separately, allows to form an exclusion domain for c and b R_{AA}



Such a *missing-ingredient* approach already have some discriminating power on models that otherwise describe the c+b R_{AA}.

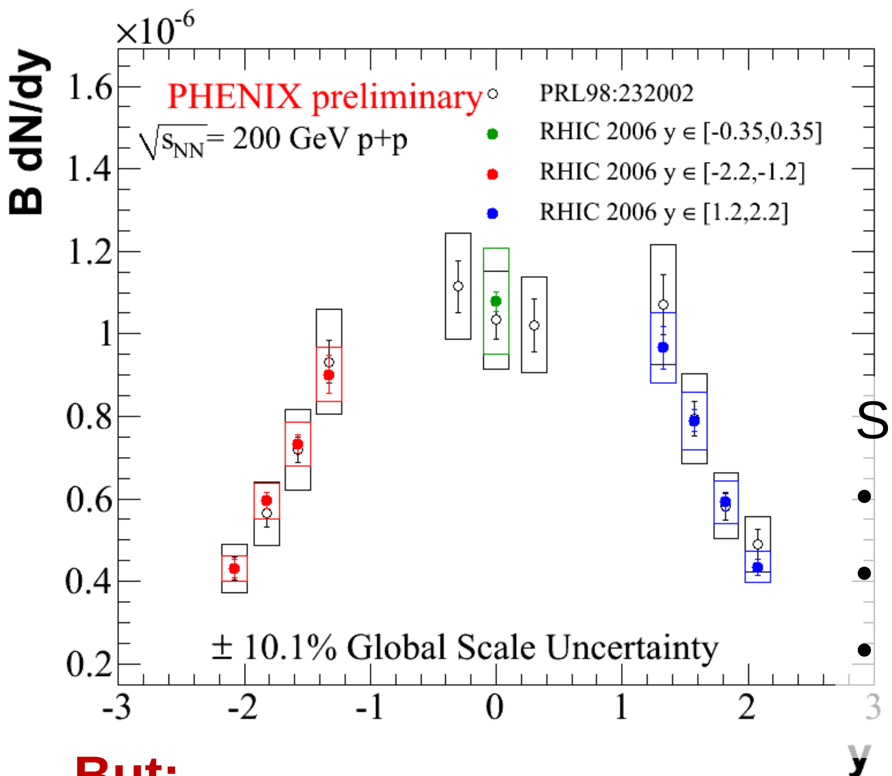
Still, a B-only measurement in A+A would be great !

Quarkonia



The *unambiguous* signature

p+p collisions



Solid reference at RHIC, with hopefully some discrimination power on production mechanism (same precision achieved vs p_T).

Some control over feed-down from :

- ψ' (PHENIX): ψ' → J/ψ = 0.086 ± 0.025
- χ_c (PHENIX): χ_c → J/ψ < 0.42 (90% CL)
- B (STAR): B → J/ψ = 13±5%
  (using J/ψ-hadron correlations)

But:

production mechanism is still largely unknown (and this affects understanding of cold nuclear matter effects).

To name a few: CSM, COM (NRQCD), CEM,

No clear picture. Need more measurements.

CSM + s-channel cut

etc.

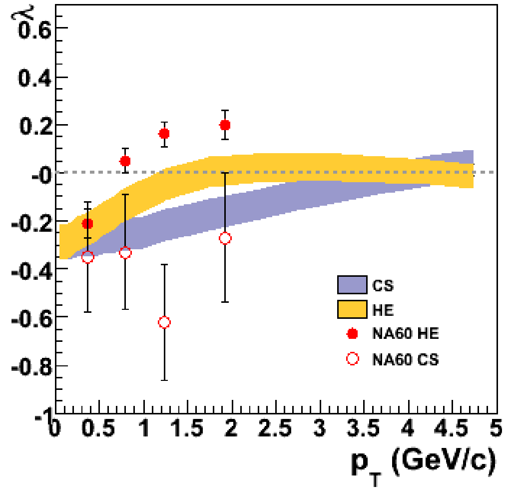
J/ψ polarization at SPS and RHIC

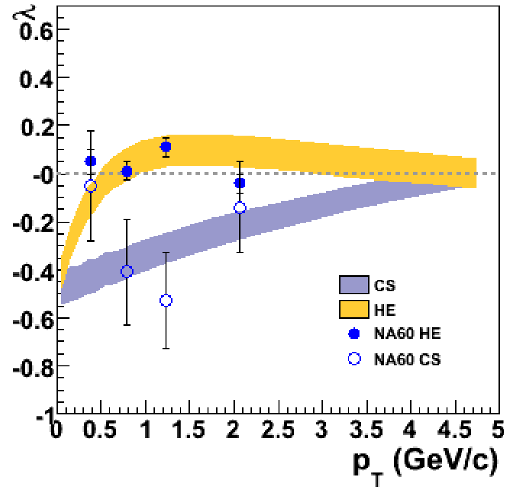
J/ψ polarization is discriminating wrt production mechanism

Measured in two different frames at SPS:

- Helicity frame
- Collins-Soper frame

CS frame would be more natural, in view of Hera-B data

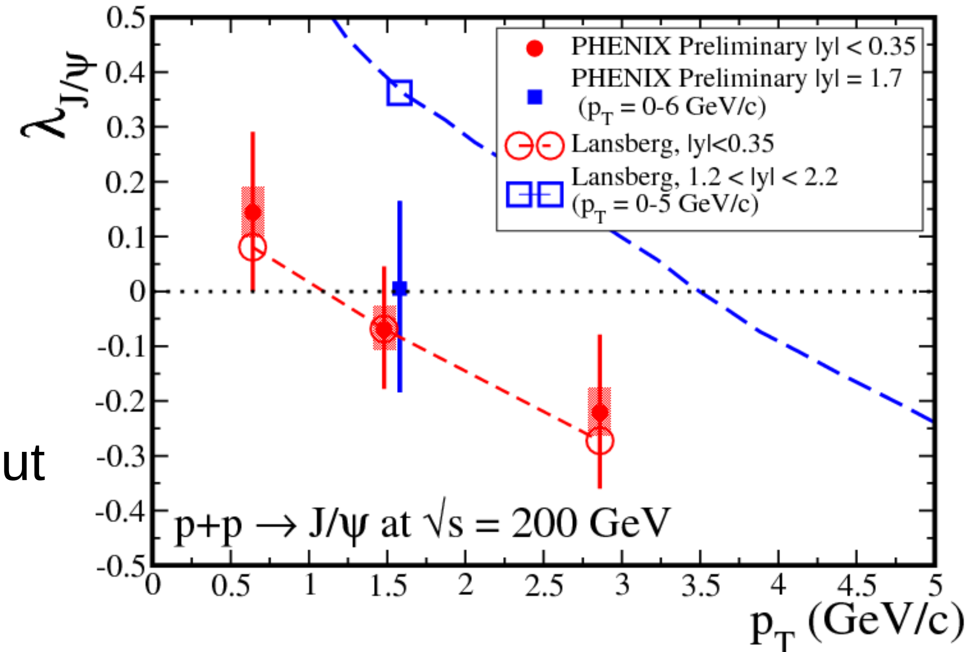




Measured in helicity frame only at RHIC in two rapidity ranges:

- at mid rapidity |y|<0.35
- at forward rapidity |y| in [1.2,2.2]

Compared here to CSM + s-channel cut

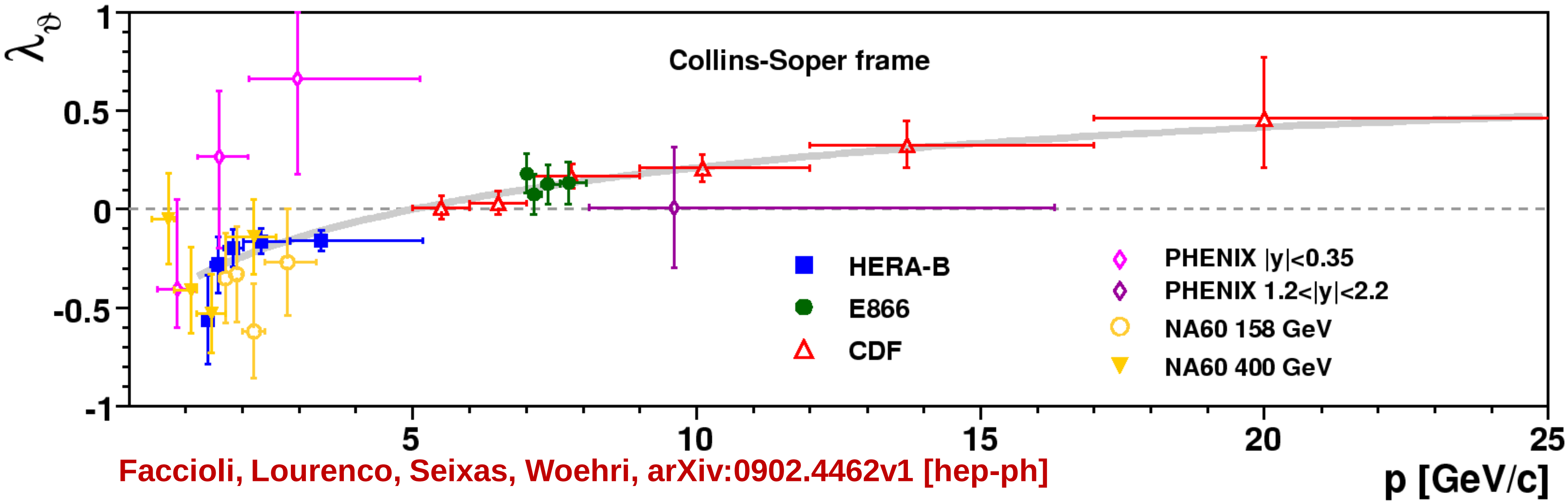


Putting everything together

- Use Collins-Soper frame for everyone
- Plot as a function of total momentum p (as opposed to p_T)
- Make educated assumption to convert PHENIX data from helicity frame to CS frame.

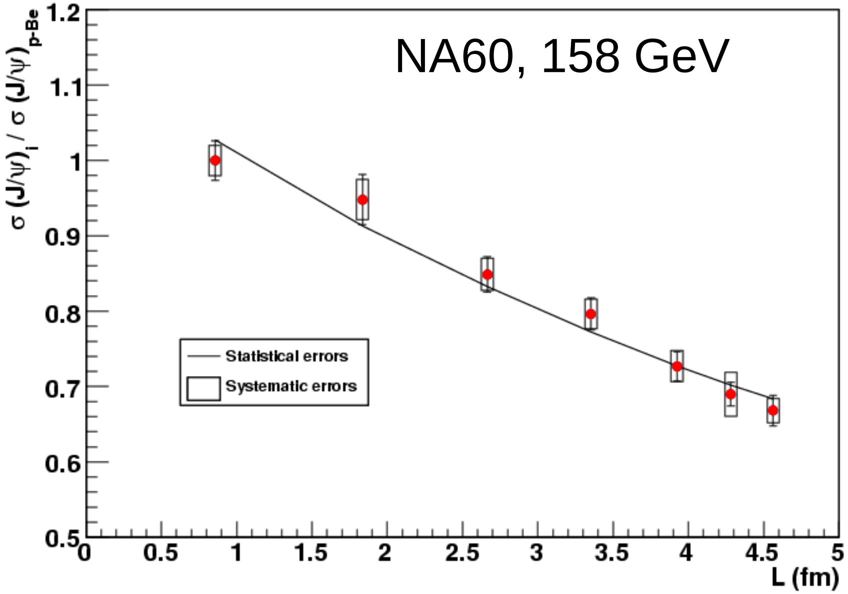
New **PHENIX** results, p-p @ 200 GeV
|y| < 0.35 and 1.2 < |y| < 2.2

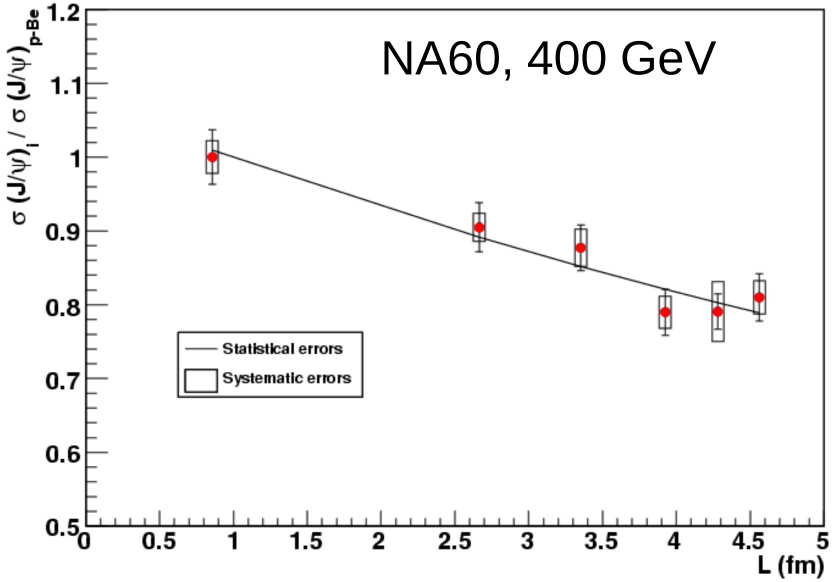
New **NA60** results
p-A @ 158 GeV and 400 GeV

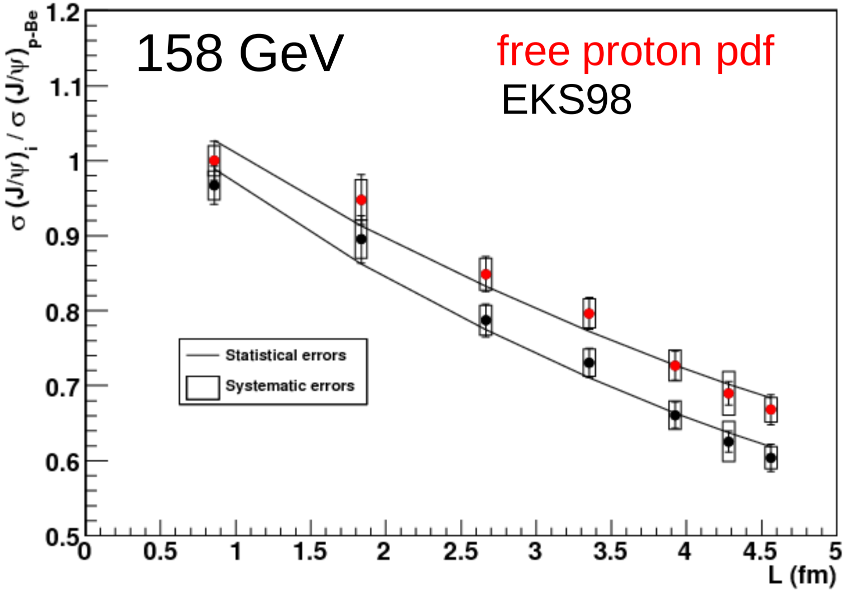


Faccioli, Lourenco, Seixas, Woehri, arXiv:0902.4462v1 [hep-ph]

Cold nuclear matter effects (CNM) at SPS







But modifications of parton distribution functions are important !

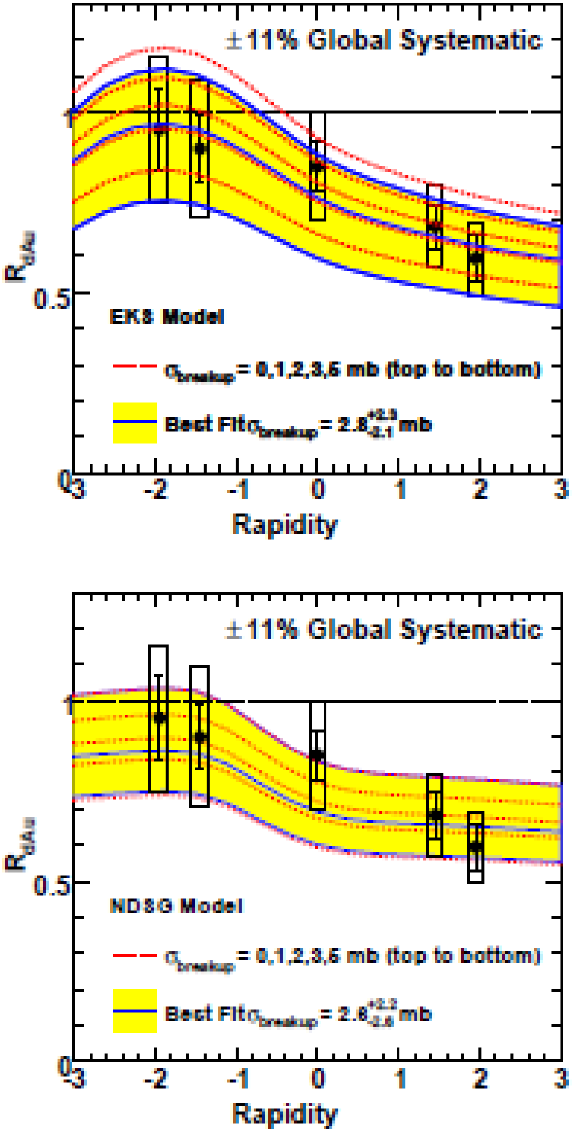
$\sigma_{abs}^{J/\psi}$ (158 GeV)

w/o anti-shadowing: 7.6± 0.7± 0.6 mb

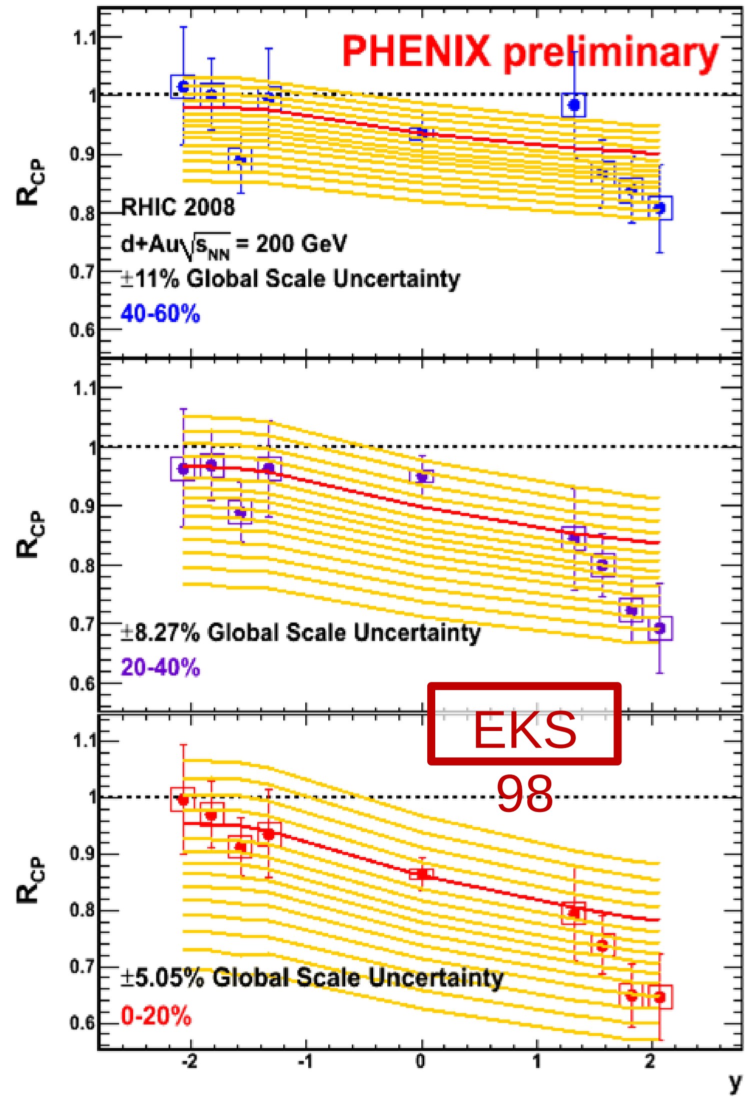
w anti-shadowing (EKS) = 9.3± 0.7± 0.7 mb

Cold nuclear matter effects (CNM) at RHIC

PHENIX, PRC 77, 024912 (2008) - Erratum



Run3 d+Au data

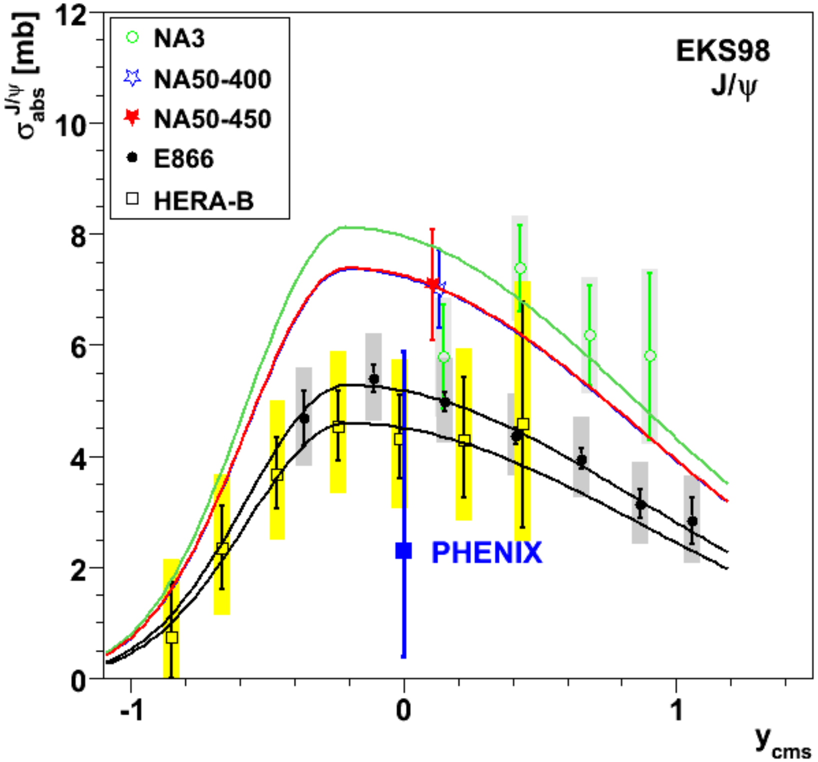


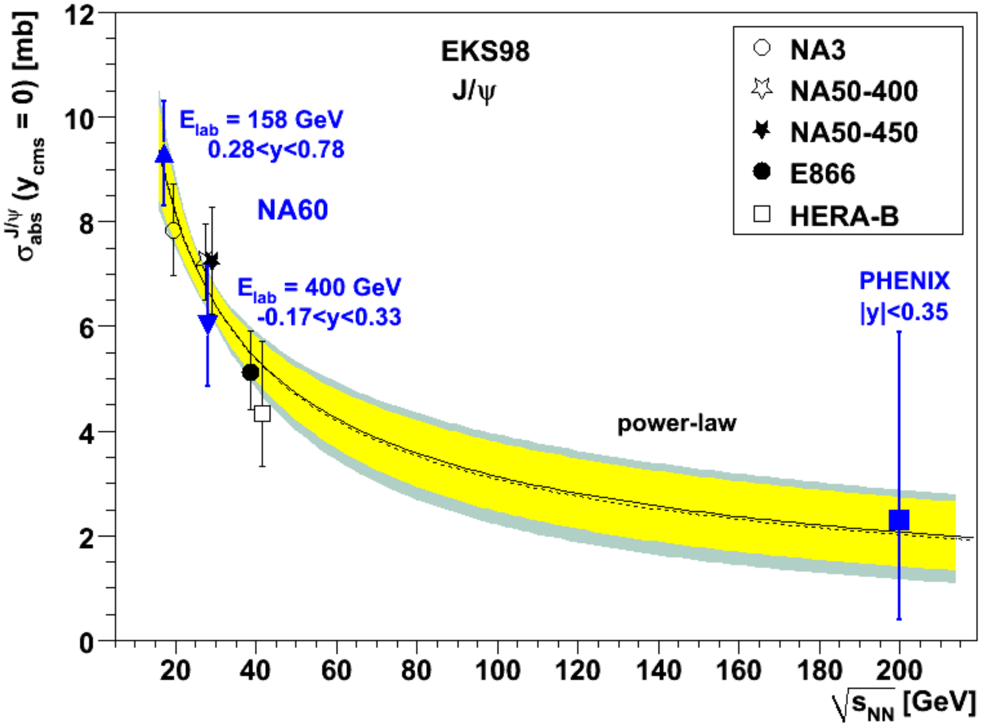
Run8 d+Au data

Putting everything together

Before QM09 PHENIX **PRC 77, 024912**

NA60





Lourenco, Vogt, Woehri - arXiv:0901.3054 [hep-ph]

Fit to sqrt(s) dependence is empirical, but might highlight a pattern.

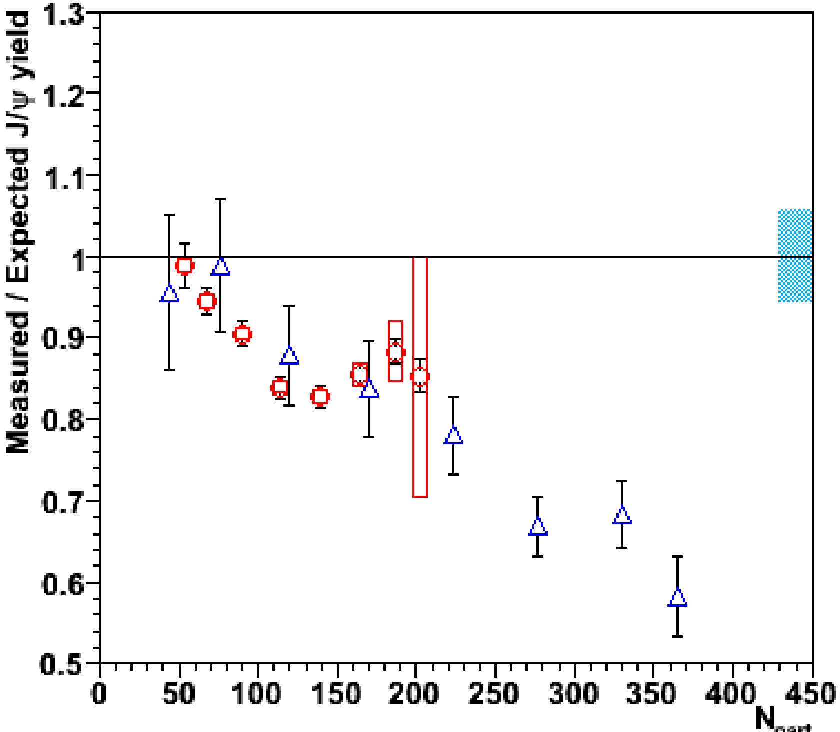
Hot effects in A+A collisions at SPS

Modifications of parton distribution functions are important ! (2)

Both σ_{abs} and (anti) shadowing must be accounted for when extrapolating from p+A to A+A collisions.

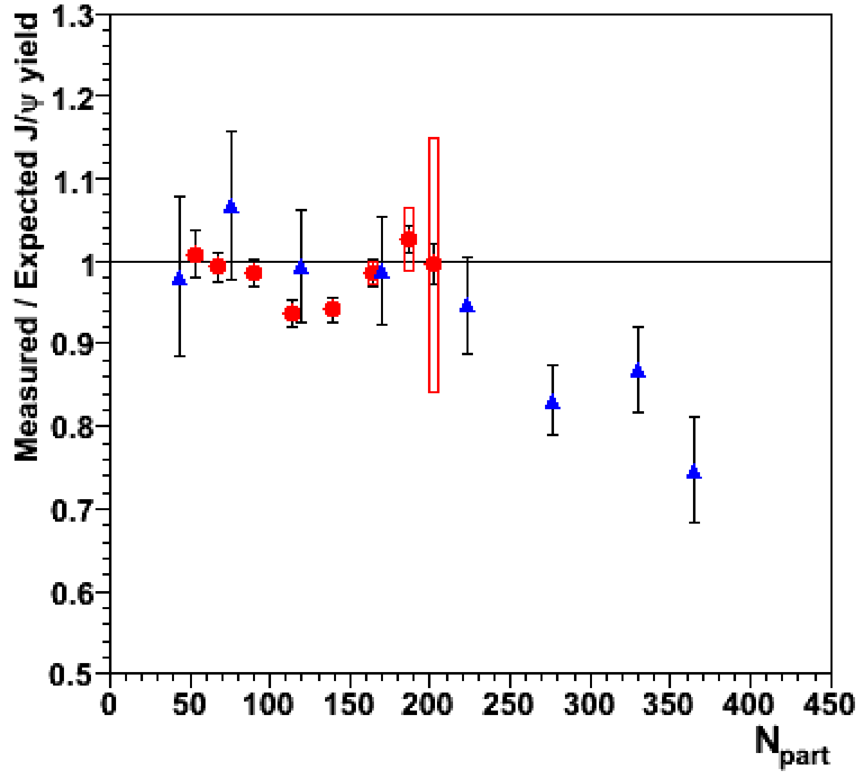
Measured/expected J/ψ

Accounting for old σ_{abs} (4mb)



Measured/expected J/ψ

Accounting for new σ_{abs} (7mb), and shadowing (EKS98)

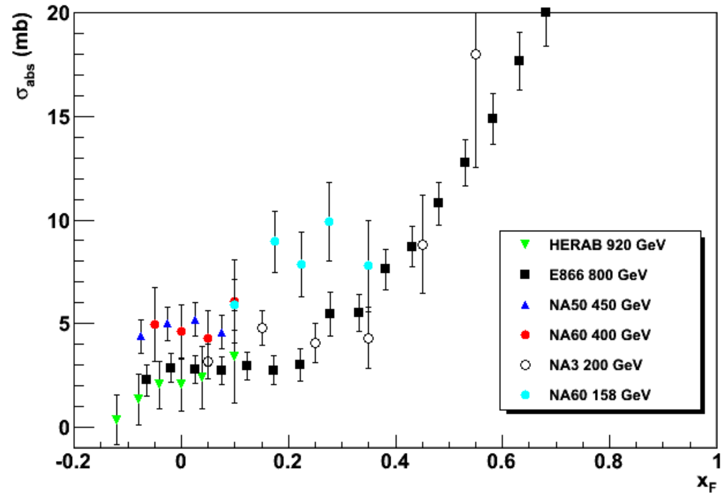


NA50, EPJ C39 (2005) 335

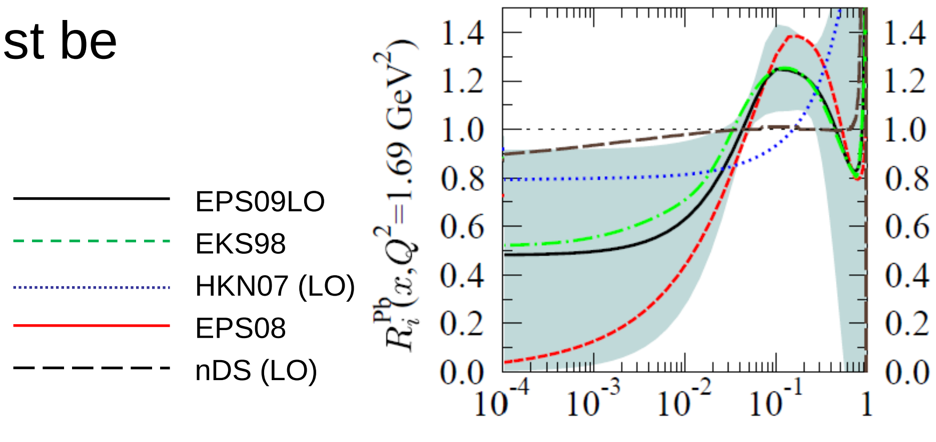
NA60, PRL 99 (2007) 132302

But … (additional complications)

1. σ_{abs} and npdf might not be sufficient to describe all cold nuclear matter effects

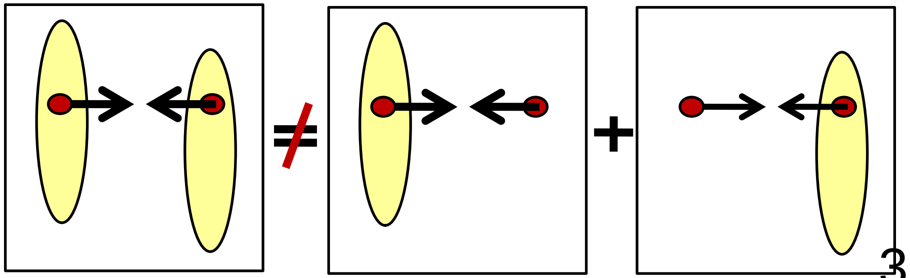


2. Nuclear pdf have error bars, that must be accounted for when deriving σ_{abs} or extrapolating to A+A collisions.



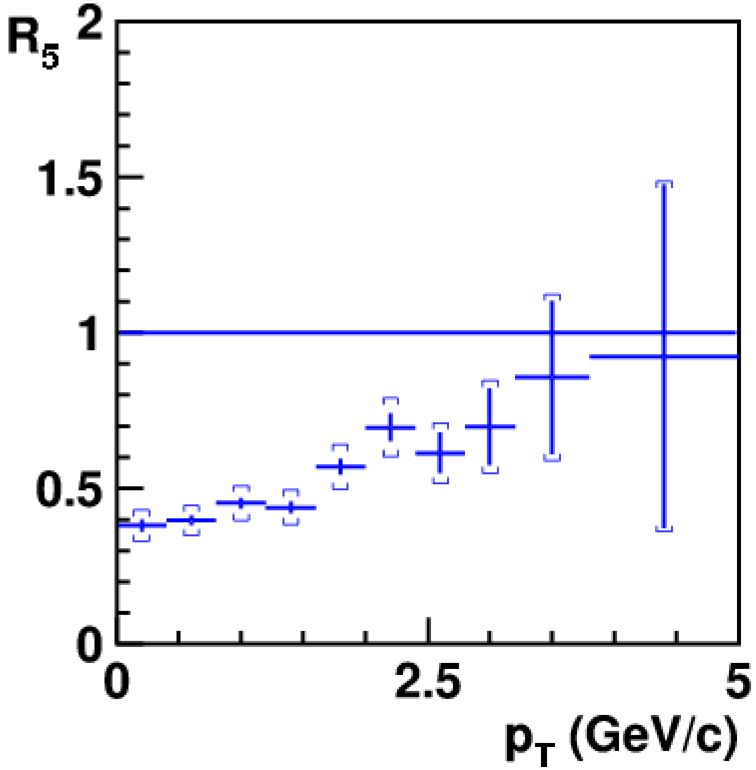
Eskola, Paukkunen, Salgado, arXiv:0902.4154v1 [hep-ph]

3. d+A cold nuclear matter effects might not factorize easily in A+A, due to gluon saturation.



High p_T J/ψ in A+A collisions (1: reminder)

RHIC is not the only place where high p_T J/ψ has been looked at in A+A !

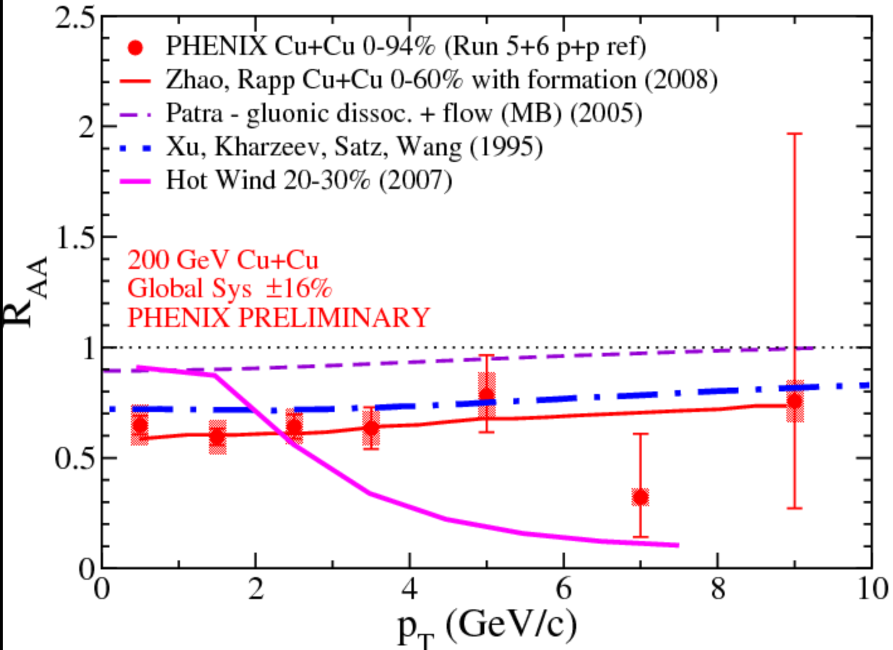


J/ψ R_{cp} in Pb+Pb collisions at SPS, measured by NA50

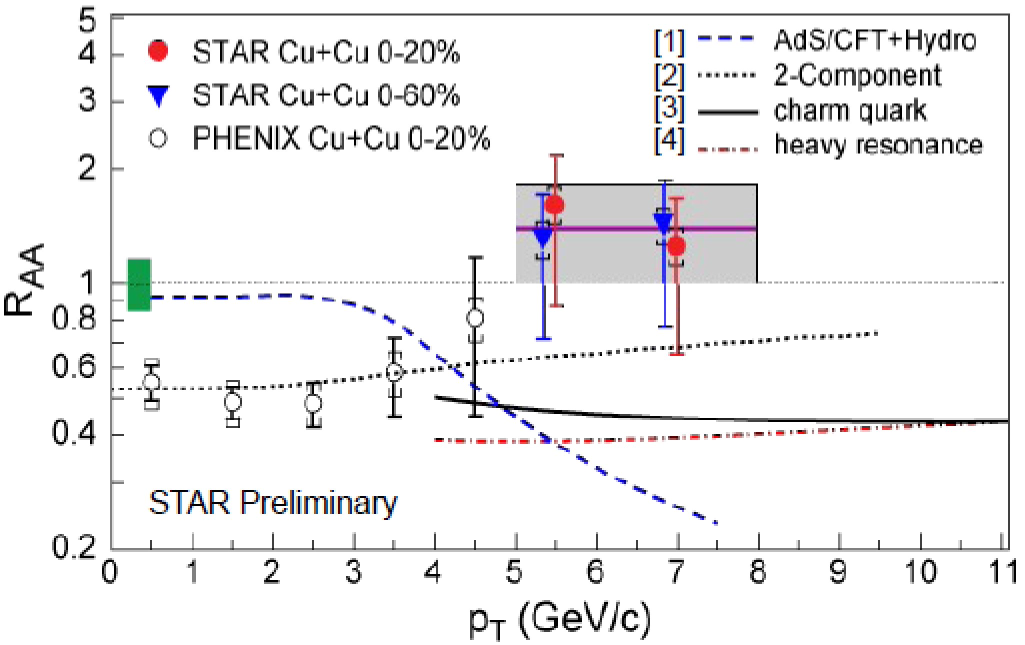
The J/ψ R_{CP} *strongly* depends on p_T (at SPS)

⇒ Only the low p_T J/ψ mesons get suppressed !

High p_T J/ψ in A+A collisions (2: at RHIC)



PHENIX Minimum Bias



STAR + PHENIX Central collisions

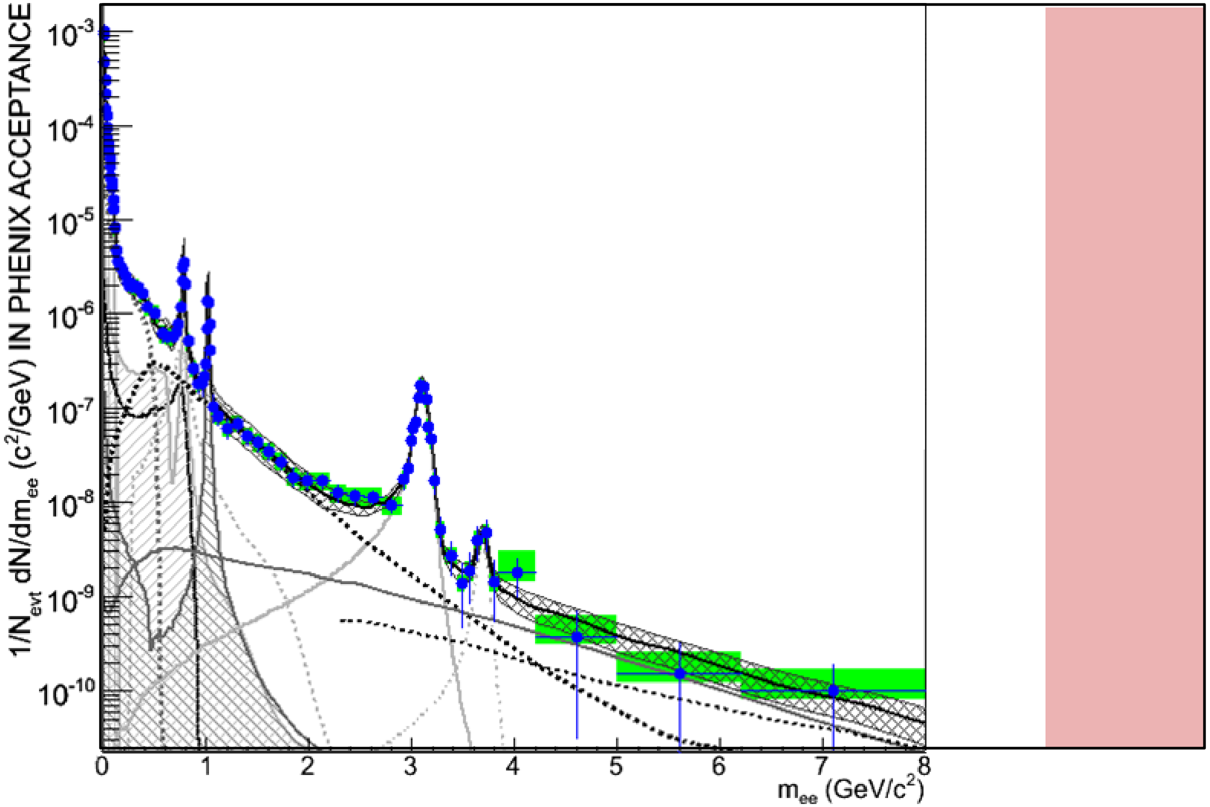
No real disagreement here (due to poor statistics).

A high p_T increase is not unexpected anyway (see SPS measurements)

Whether it is reached with current RHIC data is still undecided.

High p_T J/ψ's provide good discrimination between models.

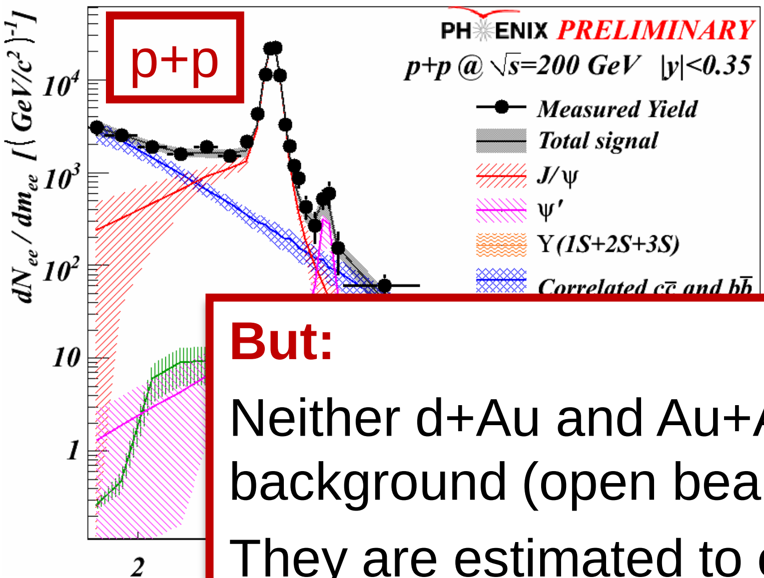
Upsilons

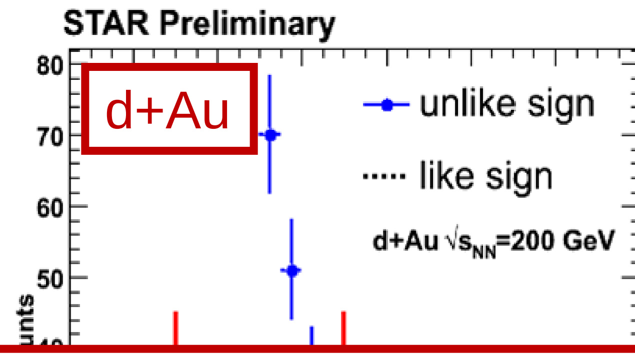


Was long considered as a job for LHC

But there are more and more upsilon measurements at RHIC

Upsilons (and high mass di-leptons) at RHIC



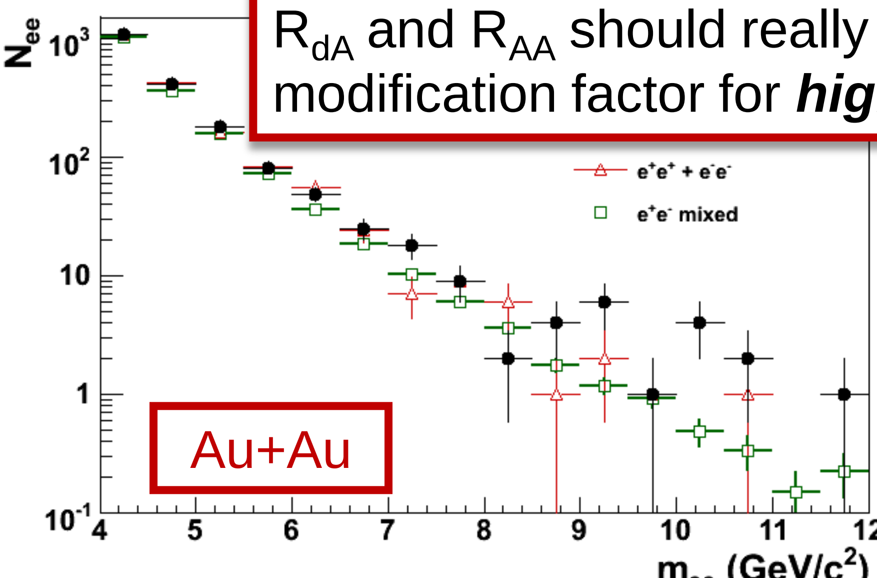


But:

Neither d+Au and Au+Au results account for physical background (open beauty, Drell-Yan) below upsilon.

They are estimated to contribute up to 10-15% (in p+p)

R_{dA} and R_{AA} should really be regarded as nuclear modification factor for ***high-mass di-leptons***.

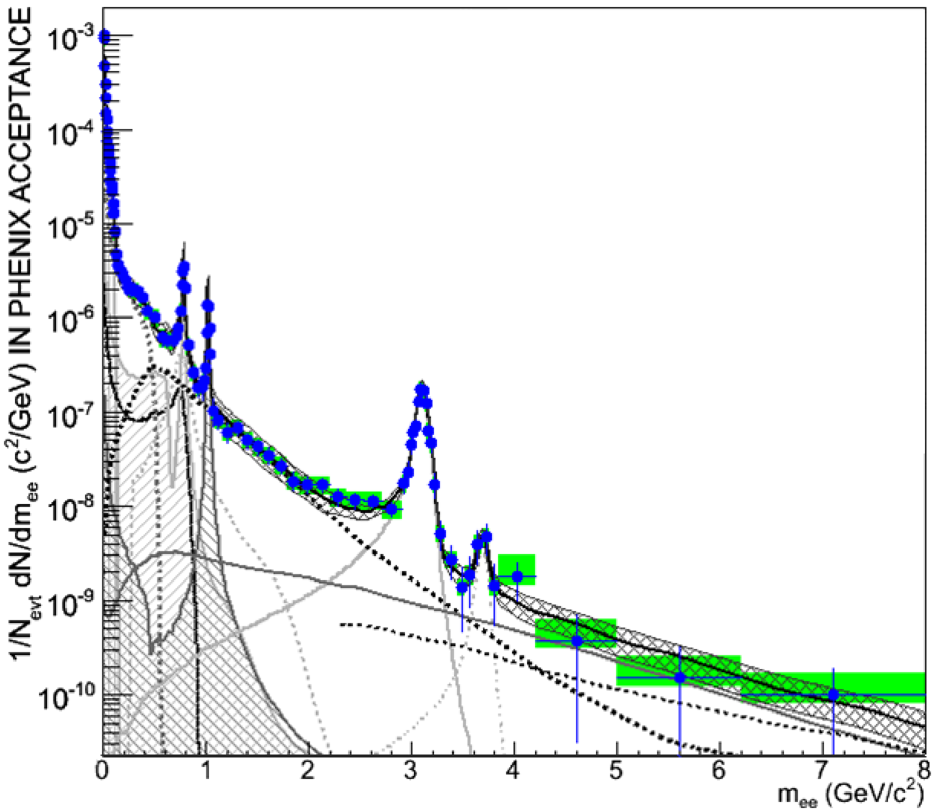


$$BR * \frac{d\sigma}{dy}\Big|_{|y|<0.35} = 114^{+46}_{-45}\ pb$$

R_{dAu} = 0.98 ± 0.32 (stat) ± 0.28 (sys)

R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.

Conclusion



Di-electron invariant mass spectra in p+p collisions at RHIC (PHENIX)

PLB670,313(2009)

We've walked through one (arbitrary) observable, that spans (here) ~7 order of magnitudes.

It is addressed

- over its full range
- in p+p, p+A, A+A,
- at different sqrt(s), y, etc.
- by both experimentalists and theoreticians,

Each part poses different challenges to both,

And leads to different physics.

Acknowledgments and apologies

Many thanks to:

- the organizers, for giving me this opportunity
- the speakers, from whom I've been stealing slides for about a week
- people who helped me shaping this presentation (Yasuyuki, Axel, Rich, Tony, Carlos, Hermine Woehri, Pietro Faccioli, …)

Apologies to:

- the organizers, for not covering all topics originally intended (notably initial conditions and possible mechanisms for thermalization)
- Theoreticians, for not giving enough details on their work in this presentation
- Experimentalists, for all results that I could not show here.